THE UNIVERSITY OF ALBERTA

MDes FINAL VISUAL PRESENTATION

By

GHASSAN ZABANEH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN

PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF DESIGN

IN

INDUSTRIAL DESIGN

DEPARTMENT OF ART AND DESIGN

EDMONTON, ALBERTA

SPRING 2006

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled:

Rhinoplasty: A Hands-On Training Module

Submitted by Ghassan Zabaneh in partial fulfillment of the requirements for the degree of Master of Design.

Supervisor

Date: May 26, 2006

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: GHASSAN ZABANEH

TITLE OF THESIS: RHINOPLASTY: A HANDS-ON TRAINING MODULE

DEGREE FOR WHICH THESIS WAS GRANTED: MASTER OF DESIGN

YEAR THIS DEGREE WAS GRANTED: 2006

SIGNED: ______________________________

PERMANENT ADDRESS:

PO Box 831206
Amman, Jordan
11183

DATED: May 26, 2006

Freedom is the freedom to say that two plus two make four. If that is granted all else follows.

George Orwell

University of Alberta

Rhinoplasty: A Hands on Training Module

by

Ghassan Atallah Elia Zabaneh

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Design

Department of Art and Design

Edmonton, Alberta
Fall 2006

University of Alberta

Faculty of Graduate Studies and Research

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Rhinoplasty: A Hands on Training Module** submitted by **Ghassan Atallah Elia Zabaneh** in partial fulfillment of the requirements for the degree of **Master of Design**.

____
Robert Lederer
Associate Professor

____
Liz Ingram
Acting Chair

____
Dr. Gordon Wilkes
Act Div Dir Plastic Surgery

____
Cezary Gajewski
Assistant Professor

____
Susan Colberg
Assistant Professor

Supervisor writes the date that the thesis is approved by committee here

University of Alberta

Library Release Form

Name of Author: Ghassan Atallah Elia Zabaneh

Title of Thesis: Rhinoplasty: A Hands on Training Module

Degree: Master of Design

Year this Degree Granted: Fall 2006

Signature

To my father and mother for
all the things they have
taught me

Abstract

Traditional approaches to learning rhinoplasty fail to train surgeons reliably in standard rhinoplasty procedures. Surgeons, therefore, are compelled to learn at the expense of their patients. This project attempts to provide a training tool that serves as an intermediate, hands-on, easily accessible and cost-effective alternative.

By acquiring data from CT scans, and employing cost-efficient 3d printing, the project took the route of rapid prototyping to create molds that mirror the nasal region and its underlying substructures. These molds are then cast separately using different materials that mimic the human tissue. The parts are then assembled into a unified and operational training module. The module could arguably improve the performance of surgeons, by providing an efficient environment to practice, revise, and demonstrate, thus reducing the risk of failure; an opportunity to learn, err, and experiment with a cheaper/disposable and risk-free alternative. Moreover, the project establishes a methodology that can enable the production of different rhinoplasty scenarios.

Acknowledgments

My sincere appreciation extended to Professor R. Lederer, my thesis advisor and to Dr. G. Wilkes, the supervising surgeon of the project, for their guidance and insights throughout the development of this research.

My special thanks and appreciation extended to R. Seelaus for her continual and unequivocal support.

I am grateful to Professor L. Ingram, Professor Cezary Gajewski, and Professor Susan Colberg for serving on my thesis committee.

Many thanks extended to Kenneth Horne for all his support during the period of my study.

To all the people in COMPRU who extended a helping hand, I am indebted for all their positive input.

Many thanks extended to my wife Veronica, all my friends and colleagues for their support and understanding.

Table of Content

List of Tables:

List of Figures

Chapter 1

Introduction

1.1. Rhinoplasty: A hands-On Training Module

The Rhinoplasty: A hands-On Training Module is part of continuing research that aims to create training tools suitable for practicing surgical procedures. The research is funded by the Division of Industrial Design, Department of Art & Design, at the University of Alberta. The research is also in collaboration with Caritas Health Group, Misericordia Hospital, and COMPRU Rehabilitation Unit in Edmonton, Alberta, Canada. The topic discussed here is the latest installment of a collaboration between the parties mentioned to develop effective training modules for surgeons. The primary aim is to develop an accessible, cost-effective environment for education of the surgical procedures associated with rhinology to enhance current training practices.

This chapter serves as an introduction to the Rhinoplasty: A hands-On Training Module topic and provides an outline and a brief description of the topics to be covered in latter chapters.

1.2. Background Overview of the Hands-On Training Module

Change is an inevitable occurrence in health sciences. New scientific discoveries and assertive developments in technology place health sciences on the route to rapid change due to greater than ever understanding of disease and knowledge of treatment. The increasing levels of knowledge are rendering previously unattainable surgical procedures a common occurrence today (Ellis, 251). This research does not adapt new approaches to nasal deformities nor technologies that are breaking into uncharted areas of medicine although, it takes advantage of newly refined three-dimensional printing technologies developed by Z Corporation® to acquaint trainees with established surgical practices in rhinology and to improve on the ways these practices are taught and transferred.

The place to start for this kind of research is to recognize the experiential and cumulative nature to developing surgical competence. Surgeons need to practice regularly to maintain the expected level of performance. The enormity of the responsibility entrusted to the surgeon by the trusting patient does not leave much room for error nor experimentation (Smith and Beatty, 58-59); "Surgeons are simply expected to possess exceptional technical skill because a patient could potentially pay a high price for a surgeon's technical ineptitude" (Dath and Reznick, 54), not to mention the multitude of problems that would arise for the surgeon from such ineptitude. This onerous surgeon-patient relationship is the norm in the operating room and it is more pronounced in rhinology due to complex nature of the procedure and small margin for error. Ample evidence points to the dissatisfaction of many surgeons with the level of their training. A recent survey of Dutch otorhinolaryngologists conducted by Van Pinxteren et al. shows that approximately 70% of physicians regarded their training in facial plastic and reconstructive surgery as insufficient (138-142).

Since patient satisfaction (Samalonis), not the clinical achievement, is considered the ultimate measurement of success, incompetence can create a circumstance of potential disaster when technique, treatment plan, or skill are in doubt. This is especially true when rhinology can introduce drastic alterations to the appearance. Such doubts are more problematic when one is newly graduated into the profession, and rhinoplasty is limited. Doubts can also occur when the surgeon tries a new approach, instrument, or technique. Arguably, such doubts will increase the stress on the surgeon and may compromise the ultimate surgical interest for the patient.

To ensure the best patient outcome, with a focus on the issues mentioned above, an intermediate “training” step such as a simulator could, in fact, improve the performance of the surgeon by providing an efficient environment to practice, revise, and thus demonstrate reducing the risk of failure. Moreover, it seems that most surgical residents need to ascend a steep/quick curve of performance and rapidly develop confidence once she/he becomes the operating rhinoplasty surgeon. Many educators in the field of medicine acknowledge this steep/quick learning curve and identify a major gap in the traditional methods of training. Vartanian et al., for example, argue the following:

> First education tools used to teach anatomy, such as textbooks, literature descriptions, cadavers dissections, lectures by experts, videos and intraoperative observations, provide a limited perspective, and lack a of the all important interactivity and feedback a hands-on experience usually provides (328).

It can be argued that such a gap persists in most areas of surgical training and particularly in rhinology due to the complex nature of most procedures in that area. Consequently, a surgical simulator as an intermediate training module for rhinoplasty is necessary, if not crucial, for the new and the experienced surgeon alike. Although not replacing traditional training methods, incorporating such a training module would add relevance, continuity and context to the former. When the necessity to practice a new approach, examine the steps of a complex procedure to foresee complications, and/or to reduce the potential of medical error arise, we witness moments when a surgical simulator could play a significant role and provide much needed training to forestall such potentialities.

Simulation as a solution is not a new idea. In the past, there have been numerous attempts to overcome the experiential gap and reduce the steep/quick performance curve in training surgeons through the use of simulation. Such attempts, regardless of the medium utilized, have always tried to capture the essence of an experience by means of realistic simulation without risking human life. In providing a hands-on training opportunity, therefore, the surgical trainee is allowed to learn, err, and experiment with a cheaper/disposable and risk-free alternative.

Typically, the majority of simulation attempts have focused on presenting surgical training as a computerized virtual reality experience. Many medical, academic and private institutions are investing considerable amount of time and money in virtual simulators—some with better results than others. An institution, such as the Electronic Visualization Lab at the University of Illinois in Chicago (UIC), has developed an anatomically correct virtual nose with a haptic interface to better help surgical trainees understand the

anatomy of the nose (Vartanian et al., 329-333). UIC and similar institutions, such as SUMMIT, gather periodically to discuss scientific and technological breakthroughs in symposiums dedicated to virtual reality simulation hosted by organizations such as ISMS and MMVR.

Regardless of the great advancements such as describing the mechanical behavior of soft tissue and deformable modeling, current virtual simulations fail to deliver some basic requirements that are crucial to successfully simulate a surgical procedure. It could also be argued that virtual reality simulators have only taken small steps towards their goal of creating effective medical simulators. These approaches still need to deliver convincingly on many issues such as realistic tactile feedback, realistic biomechanical behavior of tissues, cost effectiveness, access for trainees, and resolve issues with feedback latency, among others. Section 2.4.1 of this paper will demonstrate in detail the great enthusiasm towards implementing virtual reality modules for surgical training and outline the shortfalls of this approach. The section will forward the need to develop a tactile physical module in place of a virtual one. Although the virtual route is viable and worth investigating it will be argued that the tactile module is more practical for surgical training on rhinology procedures given the need for a “hands-on” experience in surgical training.

In comparison with virtual reality simulators, which has a wealth of technical research papers largely conducted by computer scientists, there is very little documented work or literature on physical hands-on training simulators. But with the advent of cost efficient rapid prototyping it seems that there is more willingness to investigate this option. Such an approach has the potential to provide a cheap and customizable alternative and also, by using the correct assemblage of materials, the model can sufficiently mimic the tactility of real human

tissue. Additionally, providing simulation in such a manner means trainees can repeat practice attempts wherever and whenever they need to. Moreover, the trainee will not be limited by availability of access times, geographical location and will not be restrained by their ability to understand the computer technology and/or the interface used. While there are institutions that offer the physical hands-on packages today such as Simulab Corporation, most of their focus is on general and abdominal surgical products exemplified by the TraumMan® package.

While the rhinoplasty simulator will be delivered as a physical training package, the door is not shut on a virtual option in the future, although such an addition would only operate as a supplement.

1.3. Statement of the Problem

To sum up the previous discussion, traditional approaches to rhinoplasty training, such as textbooks, dissections, videos, and intraoperative observations fail to deliver efficient and reliable training for surgeons. The lack of an easily accessible, hands-on, and cost-effective tool to practice rhinoplasty and evaluate surgical competency outside the operating room is compelling surgeons to train at the expense of patients. Therefore, this project attempts to deliver an alternative to surgeons.

1.4. The Objectives of the Hands-On Training Module

The following are the aims of this project:

1. Create an easily accessible, hands-on, and cost-effective physical training module that mirrors the nasal region and replicates its underlying substructures.

2. The module developed specifically for this project will be capable of providing a tool to train on standard rhinoplasty procedures in a patient with a Prominent Dorsal Hump and widened nasal tip.

3. The project will aim to establish a methodology that would enable the production of similar training modules with different surgical/physiological scenarios.

4. Provide a training option that would arguably moderate and, in doing so, shorten the steep/quick learning curve for rhinoplasty and has the potential to decrease surgical errors.

5. Provide an evidence-based assessment tool to aid trainers in assessing the competency of surgical trainees and their development.

1.5. Theoretical Framing of the Hands-On Training Module

Surgical training, including the use of models, is not an invention of modern medicine. In fact, historical records show some ancient societies with well developed and relatively complex approaches to surgery. The writing of Susruta, one of the earliest Indian surgical records that date back to 1500 BC, includes directions on how surgeons should practice the art of suturing on animal skins or strips of cotton, practice surgical incisions on water melons, and improve their bandaging on life-sized dolls (Ellis, 17). The emphasis by Susruta on training and developing surgical skills is a shining example of early attempts to cultivate competence in surgeons. Still, it was not the prevailing attitude of the practice, in fact, the development of surgical practice was marred with needlessly cruel applications derived mostly

from erroneous assumptions. It was not until modern times, equipped with cumulative empirical knowledge that surgical practices have come to fully appreciate the importance of surgical training.

Today ample surgical training is required. Using training modules to improve technique is being emphasized more than ever. Surgery today requires aptitude in a range of difficult skills and mastering such skills is not a simple matter. Real competence is usually the exception, not the rule. For some, competence comes effortlessly but, for most, it can be a demanding exercise (Dimon, xv). The field of surgery is no different, and hence the emphasis on training. The proposed surgical training module would therefore fill the gap and support other traditional surgical training methods which as indicated earlier by Vartanian et al., provide limited perspectives—textbooks, literature descriptions, and videos—or are costly and hard to access—cadaver dissection and lectures by the experts.

The argument advanced earlier by Vartanian et al., can also be applied to intraoperative observations. Optimal training situations should account for the presence of two elements: the first is interactivity—feedback from hands-on experiences. The second, according to Theodore Dimon, a renowned educator in his book *The Element of Skill*, is "the functioning mind and body"—the present self immersed in the process of learning "as the central instrumentality upon which all learning depends" (ix) . Dimon argues that the ability to master difficult skills relies not only on hands-on training but should also be combined with sufficient space and time to pause, reflect and examine. In short, Dimon calls for a situation where a trainee can focus on "the learning self". A patient in the operating room undergoing surgery is the focal point and should not be seen as the object of a

trainee. It can be argued that intraoperative observations, although an important part of surgical training by means of familiarizing, do not allow the conditions for the development of particular surgical skills for the trainee given that the observed and the experienced offer two very different training outcomes. In that sense, Dimon implies that learning a technique and delivering it as a service at the same time compromises the effective conditions of learning, as well as the delivery of the service itself. Therefore, when creating surgical training modules, a consideration of both elements, interactivity and immersion of the trainee in the learning process, are taken into account.

Health care services are changing at a relentless pace, clinical roles and surgical procedures have developed significantly over the past decades resulting in many new challenges and placing greater demands on health providers. One consequence of this is that the planned approach to surgical training and development has become more important than ever: not only to effectively support the rising demand on medical services but also to respond to the increasingly hostile legal environment that surgeons face today (Goldwyn, 18). The module presented here is potentially able to sufficiently respond to the challenges indicated above by offering prevention through effective training—this disposable and risk-free alternative would give surgical trainees a focused and safe environment to practice, revise, and demonstrate and opportunity to learn, err, and experiment without worrying about the challenges indicated above.

1.6. Definition of Terms

- 3DS Max: Computer-aided design software developed by AutoDesk®.

- 3DP: Three Dimensional printing is a technology developed by MIT. It is a type of rapid prototyping utilizing a layered powder solid freeform fabrication: A special printer combines layers of fine powder, which are selectively bonded by an adhesive to create a printed three-dimensional object.

- Haptic devices: "Haptics is the science of applying tactile sensation to human interaction with computers. A haptic device is one that involves physical contact between the computer and the user, usually through an input/output device, such as a joystick or data gloves, that senses the body's movements. By using haptic devices, the user can not only feed information to the computer but can receive information from the computer in the form of a felt sensation on some part of the body. This is referred to as a haptic interface" (Webopedia,"haptic").

- CT Scanning: Computed tomography uses special x-ray equipment to obtain image data from different angles around the body. The data is then processed to produce a cross-section of body tissues and organs (RadiologyInfo, "Computed Tomography").

- Magics®: Rapid prototyping computer-aided manufacturing software developed by Materialise®.

- Mimics®: Medical-imaging processing software developed by Materialise®.

- Rapid Prototyping: A technology for quickly creating physical models and functional prototypes directly from CAD models (Pham and Dimov, 96).

- Rhinoplasty: Surgery to repair or reshape the nose. Rhinoplasty is one of the most common of all plastic surgery procedures. It is usually done through the incision inside the nostrils. Nasal surgery is usually considered an elective procedure. In other cases, nasal septal surgery may be needed for reconstructive purposes, such as treating serious breathing problems or repairing an injury. Many surgeons prefer not to perform nasal surgery until the growth of the nasal bones are completed (UMM, “Cosmetic Nose Surgery”).

- STL file: “The stereolithography format is a list of the triangular surfaces that describe a computer generated solid model. This is the standard input for most rapid prototyping machines” (SDSC, “Tele-Manufacturing Facility Project”).

- Z Corporation®: An international corporation specializing in developing 3d printers.

1.7. Assumptions and Limitations

This thesis project will deliver a functional training module of the standard rhinoplasty procedures including prominent dorsal hump deformities. The trainee would be capable of performing a rhinoplasty procedure on the module in order to practice different approaches and gain practical experience without risking the potential of making irreversible errors. It provides on an actual patient a risk free option in

which one can put theoretical knowledge into practice. The module is by no means expected to fully substitute for the experience of operating on a real patient, nor would it grantee a subsequent practice devoid of medical errors. It is rather to be considered as an intermediate step that would arguably moderate the steep/quick learning curve for rhinoplasty and decrease surgical errors by gaining practical understanding of the process before advancing to the operation room.

It is recognized here that a planned approach to surgical training and development has become more important than ever to effectively produce surgeons who can answer the rising demand on surgical services. This paper will discuss such benefits and limitations by demonstrating the potential impact of the training module on the overall training program for rhinoplasty surgeons. The discussion will utilize some relevant theories of skill development. It should be noted that the subject of “how we learn” and gain practical experience is too large for this document to cover effectively hence this document will be necessarily limited to learning theories that pertain directly to the topic.

The development stage the module reaches at the conclusion of this research is the initial phase of development/prototyping—alpha stage. The successful conclusion of this stage, which will be demonstrated in chapter four, implies the viability of the concept, the manufacturing process and the product itself. Still, to further optimize the product and the process for commercial applications, requires revisions in a subsequent development stage. These revisions would be based on performance assessments and evaluations. Consequently, it should be noted that the analysis in chapter four reflects the current development/prototyping stage of the module. The analysis is based on initial observations by the author and on preliminary reactions from involved surgeons. A large scale statistical evaluation of the module,

which would be a pivotal component in the next development stage, is beyond the aims and the scope set for this research.

1.8. The Remainder of the Study

The chapters which follow will include discussion on the topics listed below:

- Chapter 2 is a literature review: a **Critical Review of Clinical Surgical Training**. The chapter will deal with the practice of training of surgeons, focus on training, learning and assessment, the principles that govern decision making, a comparison of some training approaches, and making the argument for developing a tactile training module.
- Chapter 3, **The Module**, demonstrates the Methodology: a technical chapter that articulates the design process, the initial development/prototyping stage—alpha, and responds to the problem articulated in the pervious chapters by fully describing the process involved in developing the training module; experiments, materials, instruments used, and the prototyping process of the module.
- Chapter 4, **Reflections on the Process**, is an analysis: the chapter will present the findings that resulted from the design process and the initial development/prototyping stage, analyze the layered powder solid freeform three-dimensional printing. It will also describe the advantages and the disadvantages of the physical properties of the module.
- Conclusions and Recommendations.
- Appendices: Include printed material, videos, digital images and a digital copy of this document.

Chapter 2

Critical Review of Clinical Surgical Training

2.1. Introduction

As far as I am concerned, learning is a life long endeavor, and the tools and methods suggested here are neither a solution nor a quick fix approach. Rather it is a step in a gradual accumulation of skill and knowledge and stands as a mindful alternative to current professional development practices. It is also assumed that the stated goal of medical training facilities, of graduating competent professionals, is the definite ambition of these institutions. Furthermore, it is assumed that competent surgeons, next to their properly developed surgical motor skills, are capable of revising, evaluating, and developing operational theories to adapt to unique and increasingly challenging scenarios. To achieve the goal of graduating competent surgeons the following questions need to be addressed:

- What is “skill” and how do surgeons acquire, develop and perfect needed surgical skills, and why is perfecting those skills is central to the profession?

- Can the traditional training and evaluation methods cope with the changing face of the profession (De Cossart and Fish, 11),

or are more formal methods of assessment needed to cope with an ever pronounced crisis of professionalism?

- Is time spent in a credited medical training institution considered a sufficient means to educate a practitioner who is thus qualified for a role in the profession (Richards, 7) or should there be a serious consideration to initiating new evaluative procedures beyond the exiting practical assessments to effectively evaluate clinical competence?

My experience was that simulation repertoire (excluding technical computer sciences research) in medical research is generally scarce and the validity and consistency of outcomes are inconclusive. Moreover, when dealing with regions of the head the repertoire was, in reality, close to non-existent. This recognition seems to be shared with the few who ventured into the area of surgical simulation research such as Sutherland et al. (29). The task of gathering relevant material to be used as guide and critique, therefore, was a challenge. Nevertheless, such uncharted territory is arguably full of possibilities for future innovation, discovery and opportunities to find effective alternatives to train surgeons. It was these opportunities and possibilities that provide the foundation and motivation for this project.

2.2. Skill Development Theory

It is a fact that change is a persistent occurrence in health sciences, and surgery in particular, has demonstrated a willingness to adopt new scientific innovation and technology. The rapid development in technological advancements and their adoption should be balanced by a similarly adaptive and continually evolving training curriculum. Such curriculum would draw from skill development theory and utilize

an existing volume of research about skill development. While many skill development theories have the potential to contribute to the advancement of surgical training only two, the most relevant to the topic, will be reviewed here. The first is action learning—explained in section 2.2.2. This describes a popular approach to skill training and yet one which is discouraged by this paper. The second is reflective learning—explained in section 2.2.3. This approach seems more appropriate for developing professional surgical competency. To be able to discuss those two approaches effectively one must first understand the concept of “skill”.

2.2.1. What is Skill?

> A designation among motor activities, a particular category of finely coordinated voluntary movements, generally engaging certain privileged parts of the musculature in the performance of various technical acts which have as common characteristics the delicacy of their adjustment, the economy of their execution and the accuracy of their achievement.
>
> (Tomporowski, 2)

For a surgical trainee, skill denotes a level of aptitude in the ability to perform surgical tasks in a clinical theatre that would achieve optimal and desired results. According to Dimon, skill, as it pertains to the surgical trainee, is comprised of the following elements: perception, attention, eye-hand coordination, kenisthetic awareness, the coordination of function and thought (44-64). Moreover, Dimon considers complex skills as such “...not because of the addition of complex movements, but [rather] the ability to conceive of complex movements and to coordinate them in a series while not interfering

with the natural reflexive functions upon which the specific actions are based. This results in a fluid skilled movement." (35).

For some, learning a skill is an experiential process involving a constant process of patiently experimenting and gaining insight into a process through achieving increased self-awareness. Dimon indicates that the principle act in learning a skill is not doing but rather the awareness and attentiveness to oneself is the most crucial (1). To him failure is a learning behaviour (15) and not a result. Pointing out mistakes and requesting amendments when ever failure occurs, therefore, can create a vicious circle of "…asking the student to do the very thing that brings about the problem" (6). Instead, by overcoming bad habits through doing things related to and different from the original activity can improve the likelihood of learning —Dimon denotes that the self, which attempt a training act, brings to the process of learning a skill a collection of embedded and persistent habits that might lead a person to do things by means that are faulty (127), or at least not suitable to learning a particular task.

Dimon further points out that differentiating between how adults acquire their skill as apposed to children. Adults often tackle a problem under the shadow of a larger goal; 'figuring things out' usually takes hold (11), he argues and often has the effect of leading to a process of mindless repetition of an action. Therefore, the stress is on training **intelligently** rather than repetitiously combined with long-term commitment. Training in such a manner can thus yield great results. What can further the learning process is, therefore, disengaging the exercise from possible irreversible consequences. Such disengagement would alleviate pressure that may otherwise contribute to failures and cause doubt and fear. Clearly, things like fear are not

easy to overcome once they take hold and turn into phobia of performing (25).

A function, when understood properly, happens effortlessly (165), and when developing skill, the process of gaining aptitude is a deductive not an additive process. Whereas the common misconception of practicing repeatedly would accumulate the particulars and invoke familiarity of the process, it is rather wasteful. Dimon argues that "…no amount of practice can overcome the harmful influence that the student's manner of doing exerts on his performance" (119). As previously mentioned, mastery is an economy of efforts and the specific fine motor skill activity is part of a total pattern that must involve inhibition of unwanted movement and the total pattern is the most basic aspect of the specific movement (35). Thus is formed a 'refinement of skill'. Accordingly, a mindless repetition is no skill refinement at all if not combined with and understanding of the function.

In essence, the principle act in skill development is not doing but rather the awareness and attentiveness to oneself learning combined with a long-term commitment. No amount of repetition can advance learning and skill if harmful influences are not eliminated. If actions are deemed ineffective to develop a skill aptly then an alternative to the direct method should be attempted. By eliminating harmful influences, Dimon indicates, the trainee is better capable of reconstructing proper movements by the delivery of knowledge in manageable portions and achieving milestones that will indirectly arrive at the desired skill or as Dimon calls it: divide and conquer.

The responsibility of surgical educators for providing alternative training methods is paramount since they reflect the reality of surgical

training where talents are diverse and training issues are usually personal. To be able to accommodate such a training population and be able to develop the skills of every surgeon competently, instructors need to be well versed in training theory. Dimon correctly accuses educational establishments, including the medical establishment, of faultily assuming that most "…teachers of performing skills are deemed qualified to teach precisely because of their performing ability" (123) not their ability to effectively transfer knowledge. Therefore, embracing training alternatives is encouraged. However, if traditional approaches work for some, they should be maintained. The aim therefore is to be flexible in the delivery so as to widen the circle of successful transmission of knowledge.

2.2.2. Action Learning

> Action learning is a continuous process of learning and reflection that happens with the support of a group or a set of colleagues, working on real issues, with the intention of getting things done.
>
> (McGill and Brockbank, 11)

Surgical procedures taking place today in operating rooms all around the world fit this description well. Nevertheless, it is my understanding that the previous definition is gravely at fault and, moreover, fails to recognize such a setting as an inffective learning approach for surgical training.

While it is plausible that some learning could occur in such a setting, the discrepancy here is that when the stated supreme objective is 'getting things done' learning is only a derivative side effect. As well, perfecting a task by means of mechanical repetition, which what is

more likely to occur with ‘action learning’, is incapable of providing the minimum conditions for learning to occur. Even worse it is harder to adapt when faced with variations or complications. The essence of action learning approach to training is the perfection of the mechanical and the mundane. Beyond the “realism” of being incorporated in a “real-life” situation, this approach offers little else in the way of learning. Furthermore, the “realism” offered by this mode is an attractive deception. For action learning, finding a solution to a problem at hand is what learning is all about. However, in reality for one to competently tackle a problem at hand, it is crucial to initially have developed and trained the skills (Tomporowski, 131) in a controlled environment before one is situated in a position of potential irreversible consequences—after all pilots start training in a flight simulator not in a cockpit of a passenger plane. A competent trainer would never put a trainee in such a compromising situation and ask her/him to learn and perform competently at the same time. Sufficient learning needs to occur first, working with colleagues to solve a problem at hand follows.

For effective learning to take place and to add to the conditions described earlier by Dimon, learning requires adequate time and mental resource for reflection. Learning in action approach allows only for instinctive reactions and does not give the opportunity for trainees to perfect their abilities. The ability to evaluate, theorize and make reflective decisions is crucial for professionals especially in surgery. Therefore, giving adequate time for trainees cannot be more emphasized because this process, once adapted, becomes a self-initiated norm, as indicated earlier by Dimon, and the trainee is on her/his way of becoming a competent professional. Needless to say, learning begets more learning and thus benefits of amalgamated learning accumulate in the form of experience and, likewise, skill.

Many educational institutions, however, are clamoring to incorporate action learning in their curriculum since mass education has become a reality in the post industrialized world (McGill and Brockbank, 45). It has become the obvious solution for many educational institutions encountering situations such that 'learners' are averse to reading and prefer visual [and practical] problem solving (Aldrich, xxix). As well, adding to the popularity of action learning approach is the fact that it does not require the investment necessary with other approaches such as providing more instructors to face the growing volumes of students or facilitating adequate learning infrastructure and training paraphernalia. Instead, the investment in action learning for interested educational institutions would only require partnership with business. These so called "educational partnerships" frequently fail to go beyond delivering trainees to a work site to perform a free and usually inefficient service. Unwittingly, some business enterprises, who are engrossed with reducing expenses over hiring an adequately trained labour, are quick to employ this money-saving approach in the name of learning.

It is obvious that action learning approach cannot support the conditions for proper skill development, as it was outlined earlier. Still, the supporters of such learning mode boast that it is capable of providing transformative experiences that would serve as a catalyst to thought, reflection, evaluation, and pending action (Dilworth and Willis, 155). It is highly unlikely for such 'transformative experiences' to occur with action learning when there is very little time and much at stake. In my opinion, action learning rather than being an approach that builds on the relationship between reflection and action (McGill and Brockbank, 13) is more appropriate when described as a stage suitable for mechanical and instinctive reactions. Even if some learning takes place, it should not be applied in situations where the results are

irreversible and the consequences can be catastrophic. Clearly the field of surgery is one such situation.

2.2.3. Reflective learning

Reflective learning is an approach of learning that aims to reach the goal of tacit knowledge (Schön, think in action 49) through active reflection. Reflective learning reflects a level of competence that practitioners are able to display in unique, uncertain and conflicted situations of practice (Schön, Educating 22). In almost all professions there are situations and dilemmas that are difficult to tackle relying only on research-based theory and technique. Donald Schön, who is a great authority in this field, appropriately describes the varied topography of professional practice in the following analogy:

> There is a high, hard ground overlooking a swamp. On the high ground, manageable problems lend themselves to solution through the application of research-based theory and technique. In the swampy lowland, messy, confusing problems defy technical solution. The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner must choose (Educating 3).

The apparent realization of the limitation of method-based approaches and the acknowledgment of the need for creativity and an allowance for intuition in tackling affairs is of a great importance. While this approach accepts that outstanding practitioners as having more than ‘professional knowledge’, it opens itself to the abuse of

association with junk categories (Schön, Educating 13). Therefore, any relationship between practice competence and professional knowledge need to address the following points demonstrated by Schön to resolve the question of rigor and relevance (think in action 188):

- Exceptional competency in a profession is recognized as artistry (Educating 13).

- “Artistry is an exercise of intelligence, a kind of knowing, though different in crucial respects from our standard model of professional knowledge. It is not inherently mysterious; it is rigors in its own terms; and we can learn a great deal about it by carefully studying the performance of unusually competent performers” (Schön, Educating 13).

- For professional practices applied sciences and research-based techniques occupy a limited but significantly important territory bounded by artistry of problem framing, implementation, and improvisation among others. These can aid in mediating the use of applied sciences and techniques (Schön, Educating 13).

The artistry that Schön is referring to here is in within the context of professional application. This not only means intuitive judgment and skill but also it suggests reflection in context of action on phenomena that is perceived as incongruent with intuitive understanding (Schön, think in action 241). This view might not be readily acknowledged in many professional circles, however, it is the case in surgery. A similarity could be drawn here between surgeons and an improvising group of musicians who manifest a feel for their music and make on-the-spot adjustments (Schön, think in action 55).

In accepting such reality, surgical trainers not only recognize the fact that trainees come with different talents and face varied training difficulties that require customized training approach but also it facilitate the adoption of reflective learning. This recognition would arguably promote the conditions Dimon alluded to: instructors versed in training theory, the awareness and attentiveness to oneself learning, a room available for a long-term commitment to intelligent learning, rather than mindless repetition, and most importantly, it makes a point of eliminating harmful influences, and delivering knowledge in manageable portions.

In determining a practitioner best suited for conducting surgery the following is observed: the practitioner will be a specialist who continually encounters an assortment of specialized situations. She/he is capable of developing a repertoire of expectations, images and techniques, which allow for a situation of tacit knowing-in-action after acquiring extensive experience (Schön, think in action 49-60). Having developed the abovementioned efficiently allows for the capability to amend relevant theories in order to achieve an optimal solution to a problem. Variations may occur but the stability of the practice (experience) will bring trends of spontaneous tacit behaviour. While this experience will bring benefits to the practitioner and his patients, a high level of specialization can lead to a "parochial narrowness of vision" (Schön, think in action 60).

2.3. A Critical Review of Reconstructive Training

Reconstructive [Plastic] surgery consists of "wound, fracture, and laceration management", a specialization that requires ample consultation with colleges and considerable experience. Currently, most of this experience comes from exposure in the field. Other

surgical specialists regard this specialization as exceedingly complex and requiring exceptional surgical skill that to some borders the unattainable (Verdine and Grand, 253). Interestingly, to become a plastic surgeon, initially the learning surgeon is expected to learn by watching, gradually becoming more involved in the actual procedure (Veeramachaneni, 48). To understand complexity inherit in learning the skill of reconstruction surgery a closer look at the pillars of surgical training is necessary.

2.3.1. The Nature of the Environment

The universe of a training reconstructive surgeon can be divided into two main streams: theory and clinical practice. It is important to make such a distinction early on in the discussion because each stream notably uses different methods of delivering and evaluating the learning. The theory is delivered in a classroom setting; didactic, teacher-driven and largely supported by demonstrative visuals such as videos and images. Evaluation methods for this stream are usually a written examination. These examinations are well established methods of evaluating knowledge of medical theory. The intention is that theory is first learned, and then it can be applied in practice (De Cossart and Fish, 7) which is, of course, the clinical application.

Medicine, which is a learned profession dealing with the preservation of health, has ancient origins, and was refashioned after reformation in the new image of a science-based techniques (Schön, think in action 31). It developed from humble beginnings to become one of the most celebrated professions in our modern times. Today, a great investment of resources is undertaken to create medical research centers, medical schools, teaching hospitals and a myriad of peripheral institutions. All to provide a solid base of fundamental

sciences that serves as a great reservoir of "…applied clinical sciences [that supports]…a profession geared to implement the ever-changing products of research" (Schön, think in action 38) like no other profession. Such investment comes as no surprise when the maintenance of human life is involved. Therefore, in engaging pupils to train as surgeons, medical establishments assume the role of the educator. Thus, engagement would reflect an organization and a hierarchy that is geared to make the learning a priority and a focal point. That is the assumption but the reality is different.

Such exuberantly expensive learning centres and research are expected to recoup some of the expenses by providing medical service along side education. In fact, the expectation today in light of astronomical cost of health care is that service is foremost and education is subsequent. The result is a dichotomy, a duality of focus, and a priority conflict arises from such conditions. This dichotomy arguably leaves all medical personnel torn between providing quality training for their pupils and delivering a sound service. The result is candid and predictable: both suffer. De Cossart and Fish account gives a great insight into the training process that takes place under such circumstances:

> [Learners] in surgical practice have been characterized as engaging mainly in 'magpie' learning. The metaphor is apt in that it highlights the lack of system and rigour involved, and pictures learners as scurrying around the clinical setting with a predatory eye out for what they take to be the best (or most easily accessed) jewels of wisdom, which they seize wholesale as valuable acquisitions, and rush off to store in random order in the bottom of their nest, against the day when they might

> come in handy, but perhaps without analyzing or having any idea why they are valuable…the learner rarely has the opportunity of sharing and checking out the appropriateness of the meaning they have made of the opportunity (58).

As De Cossart and Fish indicated, the reality within a clinical setting has involved surgical trainees to chaotically acquiring "…a series of pieces of wisdom about procedures, processes and factual knowledge related to generic medical knowledge and the surgical specialty" (qtd. in De Cossart and Fish, 58). This fractional knowledge is traditionally acquired from formal teaching theatres, self-directed learning and informal occasions in the intricacies of practice. The source of such knowledge, excluding formal teaching theatres, is mainly opportunistic and largely unplanned (De Cossart and Fish, 58). A profession that is so costly and with such a profound impact on society needs to introduce measures that are able to connect and assemble these anecdotal pieces of knowledge into comprehensive sets of knowledge that are indicative and reflective of the surgical trainee educational stage. But as indicated in by the following section, the problems are more profound.

2.3.2. A Crises of Professionalism

Professionals are persons who seek a broad understanding of their practice, paying attention not only to their developing competence, but also to the fundamental purposes and values that underpin their work. Professional practitioners have always been indispensable for society. Their training which is the result of committing and focusing a significant amount of resources gives them insights in specific matters difficult otherwise to have access to and

comprehended without. This expertise is necessary to solve a myriad of issues and difficulties that faces others in their everyday life and in time of crises (Schön, think in action 39). It is clear how much the modern society depends on such expertise to continue functioning. There are, however, definite signs that a crises of confidence is underway (Schön, think in action 4). For example, publicized scandals of professionals misusing their autonomy and trust serve to demonstrate the tip of the iceberg of a very profound phenomena that characterizes our society today.

The explanation that accounts for such a phenomenon is as complex as any issue dealing with human nature and social subject matter. Still, for the purpose of this paper an explanation that revolves around the effects of technological change can help shed some light on the crisis underscored above.

The last century is seen as a century of great technological and professional advances delivered with tremendous efficiency. The argument is that the last century was the time the fruits of five hundred years of humanism have ripened for picking; and the "...professions [since the reformation era] had come to be seen as vehicles for the application of the new sciences to the achievement of human progress" (Schön, think in action 31). Consequently, there is no doubt that in the later part of the last century professionalism has reached levels of efficiency, or at least seemed it did, that the faith in the process and the people behind it have attained a level close to blind conviction from members of the society.

As a result of such a high regard, many human activities vigorously pursued the characteristics and status of professionalism. For example, in the labour force only 4% was considered as

professionals in the 1900, by the year 2000 that percentage rose to 25% (Schön, think in action 7). The more influence experts exerted, the more they seemed to become bound with “self-interest, bureaucratization, and subordination to the interest of business and government” (Schön, think in action 7).

Since “experts” are problem solvers, it could be argued that rather than the ‘professional judgment’ itself was undermined, it is more likely that the exceptional demands of the public for professional judgment (Schön, think in action 7) in almost every aspect of life has fatigued the process and the concept. Previous accomplishments by professionals have made the public more reliant/expectant that professionals would come down to the “swamp” to tackle the “messy and confusing problems” (See section 2.2.3). Once such reliant/expectation has materialized many clamored to join the ranks of the experts for reasons other than problem-solving—status, financial return …etc. The result was the fatigue of the process, the loosening of the concept and the herald of the pseudo-expert: who is only an expert by implication and association. This pseudo expert infiltrated the ranks and thrived on the concept of ‘technological fix’, so much so that ‘technological fixes’ themselves became an object of mistrust. Driven to attain extraordinary rights and privileges, the pseudo expert undermined the otherwise acceptable level of professionalism, and “…swapped one set of problems to another, or worse exasperatedly worsen the problem” (Schön, think in action 10). Therefore, it has become common place that most modern day mishaps seemingly had a ‘professional’ or a ‘committee of professionals’ operating behind it.

The situation in the medical field is no different. The medical profession and its professionals are even less immune to scandals

brought by mishaps (Richards, 8). In fact, most prominent of scandals[1] seems always to do with health care which contributes directly to the loss of faith in medical professionals and the medical system itself. The subjectivity that dominates surgical training programs arguably exasperates current predicaments of medical professionalism and doctors with performance problems have continued to practice when they should have not (Donaldson, 25-26). Surgeons, by the virtue of their profession, know that reconstruction is more costly than prevention. Therefore, preventing rather than contending with the repercussions of incompetence[2] is a simpler more prolific task to handle in comparison. Prevention in surgery starts with effectively preparing surgical trainees before entering the profession and regaining professional effectiveness should hence start by reviewing the fundamental principles and traditions that govern surgery and surgical training.

2.3.3. The Traditions of Clinical Training

Calling to mind the arguments made in the Skill Development Theory section (2.2), the scene of clinical practice has traditionally favored surgical trainees to carry out a high number of procedures and, as noted, trainers and trainees alike have valued the acquisition of advanced surgical skills in such a manner (De Cossart and Fish, 7). This approach requires the surgical trainee to be engaged with patients who require/expect medical care and treatment from a competent practitioner. However, procedures today are increasing in complexity and more patients are critically ill. Such situations arguably place encumbering intellectual and emotional burdens on trainees.

[1] The scandal of tainted blood: In 1986, health professionals in Canada had to contend with a large scale contamination of hepatitis C through blood transfusion. The consequences of this scandal are still unraveling today (CBC).
[2] Such as litigation.

Evermore, it demands a level of professionalism that they are not capable to meet yet; such circumstances are compromising to say the least (Richards, 7) if not entirely dangerous to all parties involved.

As well, the learning and evaluation that occurs in the operating room is increasingly branded as uncontrolled and non-structured. To some, the concept of reflective practice, which is a crucial stage in learning, is practically non existent (De Cossart and Fish, 11) in an atmosphere where learning barely subsists with the priority of delivering optimal service. As a result, an expectation of 'action learning' is usually projected by trainers without any considerations, it seems, to the prerequisites of effective learning hence the process of clinical skill training is not only inadequate but the evaluation remains largely subjective.

Still, some who are concerned with education in the clinical stream argue that clinical environment needs to be seen as part of and not separable from service (De Cossart and Fish, 17). This argument might hold true for the later years of surgical training. That is, the service in the clinical environment at an advanced training stage, and after clearing rigorous skill assessments, can be seen as a harbinger of experience. Meanwhile, and as indicated earlier, for junior surgical trainees such a dichotomy in approach is more likely to be a hindrance to the process of learning and a portent of substandard service. It is given that the steep/quick curve of development a surgical trainee endures in the beginning of their training should not be magnified by the distractions of delivering a service.

2.3.4. The Craft of Surgery

The clinical skill development environment which requires the surgical trainee to work closely as a novice under a veteran surgeon is derived from apprenticeship training model (Richards, 11). Such an approach of training is, in essence, learning through 'reflection-in-action' where she/ "he is initiated into the traditions of a community of practitioners and the practice world they inhabit. [She/] he learns their conventions, constraints, languages, and appreciative systems, their repertoire of exemplars, systematic knowledge, and patterns of knowing-in-action" (Schön, Educating 36-37).

Such a definition appears to describe the apprenticeship model in the clinical setting accurately and many in the repertoire seem to agree that the current model of transferring knowledge in the clinical setting is apprenticeship. Nevertheless, some, such as De Cossart and Fish, differentiate the medical model from other models of apprenticeship. According to De Cossart and Fish, there are general similarities between craft apprentices and that of surgical trainees, but there are some serious differences that arise when one takes a closer look.

De Cossart and Fish argue that for craft workers the exercise of essential skills was the entire and sufficient educational activity, craft workers or 'school leavers', as De Cossart and Fish call them, would only learn skill with no theory. Once graduated, these people did not expect to see a wider form of public service. Rather, they had a fixed job plan and might never expect wide autonomy in their work. They will not seek further formal learning, would not become graduates, nor would they pursue long-term professional development. In contrast De Cossart and Fish argue that the surgical trainee would have to be the opposite of all that has been mentioned above and goes as far as

claiming that modern professional surgeons are both physicians and artists. While the notion that surgeons could be both physicians and artists is plausible, the majority of the claims De Cossart and Fish make above, to differentiate surgical apprenticeship from other apprenticeships, are faulty and largely uninformed for the reasons outlined below.

The reasoning De Cossart and Fish use to advance and distance the apprenticeship of a surgical trainee form others in crafts is at least presumptuous and more likely discriminatory. De Cossart and Fish assume that all craft apprentices enter a training program with the same low-level of capabilities and maintain the same level of interest, or rather disinterest, throughout their careers. On the other hand, De Cossart and Fish assume that all learning surgeons enter with the same high-level of commitment which they maintain throughout their careers. First, to make such a claim is to claim to perceive the real motivations of individuals behind their decision to enter a one profession or another, which is, of course, unattainable. Secondly, many accounts that study professionalism and professional behaviour question not only motivations but also the level of interest of professional practitioners have at an entry point into the profession or otherwise (Schön, think in action 12). Thirdly, many studies indicate that we are becoming a knowledge based society which thrives on staying up-to-date and, just for that reason, many employees feel that they are overqualified for their jobs (Sawchuk, 48).

Taking the former into consideration renders De Cossart and Fish claims doubtful. Discounting changing aspirations is certainly a misjudgment, and not reflective of reality in any profession. Career aspirations change with time and as such any profession is capable of apathy as well as ambition (Schön, think in action 5). Work being a

human activity always leaves room for more creativity, development, interpretation, and shifting aspirations as conditions change.

Furthermore, current educational and social systems allow for both aspiration and apathy to flourish despite the nature of the profession. For example, an apprentice electrician might start as such, but concludes her/his career as an engineer. A surgeon, as well, might start as such and concludes her/his career with a mediocre performance and maybe a scandal (Schön, think in action 4). Furthermore, De Cossart and Fish argue that the clinical aspect of surgical training is largely based on apprenticeship and though it may require a higher level of entry (8-11) still it does not change the nature of how the knowledge is being transferred—a novice will always learn from an expert.

While it is my opinion here that 'the curriculum for the general professional practice of surgery' falls in unison with the general model of apprenticeship, it should be noted the only difference observed is that "...the more powerful the professions, the more serious the dangers of laxness in concern for public service and zealousness in promoting the practitioners" (Schön, think in action 12). Therefore, it is accurate to say that how surgeons learn today largely consists of "...investigating formal teaching session along with the number of operations that they are able to perform" (De Cossart and Fish, 11) under the supervision of a senior training colleague.

2.3.5. The Limitation of the Current Training System

Historically speaking, Halstead is credited with the introduction of the graded responsibility and experience apprenticeship model (Dath and Resznick, 54). This model reflects the approaches

conducted in many of the European training systems that use a similar model for training the skills of surgeons (Dath and Resznick, 54). What used to be a suitable model for preparing a competent surgeon in the past, however, is arguably facing more challenges today due to the increasing complexity of today's profession.

While De Cossart and Fish argue that there is no rigorous training capacity at all in the current system: service of the patients seem to always take precedent over teaching while surgical trainees are generally left with a feeling that there is very little window for them to learn from the situation (11). Others, such as Richards, argue that there is a resemblance of a structured training system especially with reforms described by Calman. However, the Calman reforms significantly reduced the period of training, and hence, a surgical trainee becomes less likely to have senior training colleagues watchfully monitor her/his learning process throughout a significant period of training (Richards, 11) thus rendering some opinions describing the preparedness and competency of surgical trainees under the Calman reforms as lacking.

In reflecting on the earlier arguments of De Cossart and Fish, and the arguments of Richards and to better understand the scope and the complexity of preparing a competent surgeon, the following is a list of desirable skills for a surgical trainee compiled by Goode, in his study The Clinical Link (103):

- Communication skills
- Surgical skills and manual dexterity
- Knowledge of basic sciences
- Post-operative management
- Knowledge of theoretical clinical skills

- Teaching and learning skills
- Knowledge of clinical skills
- Management and leadership skills
- Decision making-treatment options
- Research and data analysis skills

One can see that some of these skills can be greatly developed when training under a supervising trainer in a hospital setting. In such a training environment, a surgical trainee will quickly need to call upon her/his communication skills, the knowledge and understanding of basic sciences and theoretical clinical skills, research and data analysis. However, a surgical trainee will have a more challenging time in practicing skills such as post-operative management, leadership, decision making-treatment options, and perfecting teaching and learning skills. More than ever, the window to train critical skills such as motor skills and manual dexterity is extremely small due to the nature of the service oriented environment a surgical trainee functions in.

If one considers the situation of a musician who needs to practice their skill repeatedly to maintain a professional level, surgeons need to practice their surgical skills whenever an opportunity arise to maintain a professional level of competence with particular surgical procedures (Sutherland et al., 2). Just as a musician's aptitude will decrease the less a musical piece is practiced so to is the case for surgical trainees.

2.4. Accessing Effective Skill Training

> [Skill is a] complex, highly interactive event, involving a flow of sense data, motor processes, ideas and emotions. Each has mental and physical components as well as subjective and objective aspects, and requires management of a great deal of information and awareness of the underlying realities.
>
> (Pappo, 1)

Technical skill is not always married to excellence in intellectual ability. The accepted rule in surgery is that there is a wide range of manual competence between surgeons (Richards, 13). Dath and Resznick state that "a skillfully performed task comprises 75% decision-making and 25% manual dexterity", nevertheless, this 25% is likely the largest individual component of a surgeon's expertise and one not readily assumed by other specialists. It is therefore vital to optimize technical training and to ensure that the graduates of surgical training programs have acquired a high level of technical expertise (Dath and Resznick, 54). Nevertheless, skill development pertaining to motor skills, dexterity, eye-hand co-ordination and spatial skills has the least window of practice, and they seem to be much more difficult to assess (Richards, 11).

This situation has been noted in the clinical setting and the reason is that learning centres make providing competent service to the public a priority and education is secondary. On closer examination, however, the current methods available for surgical trainees to practice their technical skill reveal some grave shortcomings stemming from their limited scope to provide for appropriate training and evaluation as well as the legality and morality of the use of some (Sutherland, 1).

These training methods are presented here in two groups: the first is the standard (traditional) training methods; which include patients, cadavers, live animal models; these are elaborated for their relevance to the topic. This group naturally includes the instructive teaching and learning methods form textbooks, images, and video. Those that are not elaborated upon here are omitted due to their remote relevance to the issue. The second group includes more recent additions under the banner of "training simulators": virtual reality simulations and the tactile-hands-on simulators—the focus of this paper. While training simulators will have more expanded discussion in their own section, traditional training methods are briefly mentioned here for reasons of contrast and distinction:

- Patients: while some are open to the fact that doctors need to come across real life situations to learn, most ill people come to a hospital expecting prompt and competent care, and will look upon training doctors with suspicion and distrust. The idea of introducing real patients to a learning situation raises a set of ethical issue "...surrounding the degree of a resident's participation in a particular patient's operation is not uniformly delineated. [As well] it would be difficult to regularly obtain consent from patients to have residents be assessed for technical skill during their surgeries, since the testing of competence implies the possibility of a lack of expertise. [Finally] it is difficult to standardize surgical procedures, to standardize the resident's level of participation in the case and to standardize the frame of reference as to the level of expectation for performance by different levels of trainees" (Dath and Resznick, 56-57).

- Cadavers: while they are considered a great resource, they have their own set of problems that prohibits them from becoming a universal candidate for training. They are inappropriate to use for evaluation on regular bases; they are capable of transmitting diseases; there are only available in limited numbers; they are difficult to transport and require a special theatre of operation; even though they have all the necessary anatomical features needed for training “the feel of the tissues is different and there is no bleeding to control” (Dath and Resznick, 57).

- Live animal models: These share many of the advantages and disadvantages with cadavers, but also pose a question of relevancy and a harder ethical question regarding their use.

The position here is that while many practitioners consider accurate diagnosis and excellent decision-making to be most important aspect of the discipline (Newble and Southgate, 47-50), there is compelling reasons to concentrate on developing technical skills by introducing innovative measures and reduce reliance on the traditional methods discussed above (Sutherland et al., 28). To that extent, there seems to be a growing interest in acquiring new methods to assess practical skills. As Newble and Southgate indicate, combining objective assessments with peer review which includes an informed scrutiny of audit data and a direct observation of practical procedures is acceptable at present and until well developed methods arrive—those would be capable of objectively assessing the skill sets needed for an entire procedures (47-50). Simulation positioned as a probable training method for evaluating future surgeons is scrutinized and assessed in such a light in the following section of this paper.

2.4.1. Virtual Reality Simulations

Virtual Reality Simulations are a relatively new form of training in the medical education. This new and exciting training option has great promise to solve not only medical training dilemmas but also many other professional training predicaments. It will be discussed here in detail for its extensive relevance to the project developed in conjunction with this paper.

Virtual reality simulation (VRS) refers to an "...interface paradigm that uses computers and human-computer interfaces to create the effect of a three-dimensional world in which [a] user interacts directly with virtual objects" (Bryson, 1). A similar definition is derived from a medical report examining the surgical simulation: "Virtual reality is a computerized, three-dimensional form of simulation, which allows participants to become immersed in an artificial, yet believable, environment and be able to use components of their senses in real time" (Sutherland et al., 1).

Virtual reality simulation has obvious advantages. These Virtual reality simulators ingrain knowledge more effectively (Hughes, 75) by interpreting a process abstractedly; all distractions removed and the feedback is usually immediate. Virtual reality simulators also allow for repeated training of complex processes and present them realistically (Pappo, 47) which otherwise would be expensive or impossible to repeat or replicate. For surgical training in particular, the virtual reality simulation option offers a condition of repetition of the same exact conditions which is hard to produce in traditional training forms. It also creates a make-believe environment that emulates real situations and therefore helps convey information more effectively (Pappo, 5). It is a visual resource that is easier to commit to memory and call upon when working through a real life situation.

Virtual reality simulation presents dangerous and costly training scenarios in a benign setting which is crucial for preventing dire consequences and mistakes. Virtual reality simulation becomes a very useful alternative when the environment is potentially harmful for the participants or the subjects, the operational system is too expensive to operate for practice or the operating window is too short for adequate feedback (Pappo, 49). Such flexible characteristics make virtual reality simulation an attractive alternative to traditional medical training methods

This, however, it is not all wonderful news for surgical training, at least not in the current state. Most of the advantages and flexibility described above can be viewed as shortfalls as well. Virtual reality simulation is still an infant technology that requires yet ample research and investment to bring it to an acceptable operational standard that would benefit surgery or qualify it as a bench for competence testing. It is heavily dependent on the advancement of many other technological fields. For example, current virtual reality simulation systems fail to deliver reasonable soft tissues properties (Liu, Kerdok, and Howe, 67) or an acceptable level of realistic feedback. Moreover, current haptic devices are known for their high latency feedback–simulating realistic low latency feedback systems are critical if surgical trainee are to use such tools to develop their technical skills. In surgical simulation research circles it is understood that "...surgeons rely on tactile sensory information while operating, thus, simulating information effectively is necessary for realistic training" (Batteau et al., 186).

The realization of realistic virtual reality surgical simulators first needs to overcome some difficult milestones. The first is the acquisition of valid biomechanical information and the second is

developing sufficient computing power to run complex simulation on personal computers (Liu, Kerdok, and Howe, 72). On a conceptual level, developing a complex and reliable virtual reality simulation generally requires an extensive knowledge in information design, behavioral sciences, physical sciences, and computing languages (Pappo, 45). As well it is reported by Towne that simulators can generate reluctance or inability by the user to exhibit true scientific exploratory behavior such as forming hypotheses, making predictions, conducting tests and drawing conclusion without support (115).

Other views indicate that virtual reality simulation is only capable of measuring skill at operating the simulator which does not correlate well with the skill level expected to handle biological tissue (Richards, 11). Therefore, it could be argued that a virtual reality application, developed by one professional for the convenience of another, in spite of ample arrangement and preparation, can be compromised by unintended deficiencies. In short, this is due to developer misinterpreting tenets and conditions that are owing to the inherently complicated operational dynamics of real-life situations. In that light, it is prudent only to develop a segment of an experience and not strive to reproduce reality, because arguably doing such can create an unworkable event (Jones, 10).

Avid supporters of virtual reality simulation in medical training draw parallels from the successes of flight simulators (Richards, 12) and space industry (Hughes, 79). The belief is that what these simulators can do, surgical training virtual reality simulation ought to do as well, because all these virtual reality simulation deal with the maintenance of life in threatening situation. While superficially the analogy seems correct, a closer look reveals a stark difference between the situation of flight simulation and medical simulation. Flight

simulators are simulations designed to emulate a finite machine invented by a human being hence the emulations are very efficient because the mechanisms, operations and apparatus are fully understood. On the other hand, the inherent complexity of surgical virtual reality simulation stems from the fact that it deals with a complex system that supports life that developed over millennia of evolution; a system with which our knowledge is superficial at best. Therefore, the correlation between flight simulators and surgical simulators is weak.

It is understandable why medical trainers yearn for a virtual reality simulation on par with the flight simulators. With trainers seeing what simple simulators are capable of doing in way of transferring skills to the learning surgeons, they conclude that a product developed with more complexity and realism would be a great assistance in "…selecting, training, and continuing education of surgeons" (Richards, 13). What medical trainers fail to see here is that they are requesting a simulation reflective of a living system that is not fully understood. The humbling realization is that we are only able to achieve limited success in such an endeavor until the complexities of living systems are better understood and better systems are developed that take the complexity of this specific situation into consideration.

When it comes to surgical training, a question of effectiveness of simulation asserts itself: is virtual reality simulation able to provide a better environment for training and evaluating surgical skills? The vast majority of validity studies of virtual reality simulation have shown mixed results, overlooked important aspects of validity issues, and left many others untested (Sutherland et al., 3).

A medical review into the impact of surgical virtual reality simulation conducted in 2003 concluded that these virtual tools can

only "...achieve knowledge transfer rate of 25-28%, which is much lower than that the 50% (or more) that can be achieved by flight simulators" (Sutherland et al., 2). As well, the study makes a note of the poor rating of evidence because most RCTs were flawed and the inconclusiveness of results related to small sample sizes and validity issues.

Such low levels of knowledge transfer is also compounded by the enormous resources needed to develop such simulations. More research must occur "...to determine just how much skill transfer a surgeon can expect from a virtual operating room situation [if] the future of any serious proficiency training for medical personnel [would] include the ability to utilize simulated situations and equipment" (Hughes, 80).

This brings us to the central argument of this project. In developing a hands-on training module, the goal of this research is to highlight the advantages of virtual reality simulation, while minimizing their negatives by providing a tactile simulator that is capable of presenting the region under study realistically to promote effective training and skill development to surgical trainees.

2.4.2. The Hands-On Training Simulators

> [A simulation] is an event in which the participants have roles, duties and sufficient key information about the problems to carry out these duties without play acting or inventing key facts. They keep their own personalities but take on a job, duties, and responsibilities and do the best they can in the situation in which they find themselves.
>
> (Jones, 18)

Others describe them as a "...variety of selectively interactive, selectively representational environments that can provide highly effective learning experiences" (Aldrich, 270). Essentially, a simulation describes a situation where participants can assume functional roles by utilizing information provided specifically to solve a particular problem. This environment should allow for mistakes and failures and thus a simulation setting must be considered as a non-taught event (Jones, 9). Many researchers indicate that simulation as a training tool is gaining popularity due to the nature of today's students which are described as pragmatic, increasingly visual problem solvers, computer savvy and craving interaction and personalization (Aldrich, xxix). The claim is that such tools are breaking down the artificial barriers between learning a task and doing a task (Aldrich, 277).

The definition of surgical simulation is slightly different. According to a report developed by Sutherland et al. and ratified by the executive of the Council of the Royal Australian College of Surgeons, the definition of simulation is "...a way of representing situations that are likely to actually occur, with sufficient realism to suspend the disbelief of the participant" (1). For any simulation to be successful it should allow a trainer to practice detailed processes repeatedly to ensure the development and the retention of the skill (Hughes, 75). As well, it is important to avoid incorporating conflicting methodologies (Jones, 19) which, though introduced unintentionally, have adverse effect on surgical training.

Simulations are not a universal answer. Most ideally they are used for rehearsing a process or emphasizing the practical approach. Simulations are suitable for developing communication and decision-making skills which in turn reflects upon behavioural abilities (Jones, 44). A pivotal character of simulation environment is that it is a non-

programmed experiential learning thus it cannot be rehearsed (Jones, 10). If users accept the conditions, participants in a simulated environment are in charge within their own sphere and, as such, they affect change and respond to events (Jones, 13). Since this is an experiential event what happens inside the mind of the participant is important; the anticipation of thoughts and approaches, behaviors and emotions, can be employed as a measurement in development phase, and as evidence for the achieving the desired objectives in post development.

When personal development is an objective, simulation has advantages over other methodologies. The following is a list of those advantages derived from the third edition of Simulations, a Handbook for Teacher and Trainers (Jones, 47-49):

- The environment in a simulation is safe; it is open to error and experimentation.

- They perform a specific functional role; they don't allow for open-ended role play.

- Simulations do not promote competitive behaviour, however they allow a different range of behaviours, that in the context of personal development.

- Simulations allow for authority to affect; the problem solving is always expected to be in a context of a functional role or a job.

- They are almost unmatched for "...revealing human and ethical qualities, all part of the concept of personal development" (Jones, 48).

- Simulations have strong connection with reality; even though they are presented in abstracted form lessons learned form simulations are usually applicable in real life.

More in relation with the advancement of surgical training and evaluation, a simulator would be capable of providing the following:

- Help trainers to select promising pupils on an entry level (Richards, 13).

- Further into the training it would serve as a tool for a benchmark training and evaluation and even certification (Hughes, 79); although that would require well developed simulators (Richards, 13).

- It is capable of providing a constant and expected level of difficulty, hence allowing surgeon to train on a specific skill multiple times without the need for waiting for a patients to seize an opportunity to train.

- Also the removal of the patient eliminates the pressure to be sufficiently qualified to deal with complex conditions, and removes the dangerous consequences of error.

- Arguably it would make considerable savings in resource by eliminating unsuitable candidates.

- Improve performance before attempting a procedure on a patient, and build sufficient confidence with it.

- Create a focal point for discussion surrounding the mastery of particular surgical procedures.

- It will help create an archive for the trainee and track evidence of progress.

In addition to the previous and to make a training situation most conducive to the transition of knowledge, an effective simulator requires an effective environment and context. That is, all spatial relationships in the training theatre should be considered. The organization of the space radically affects how teaching is conducted and learning facilitated. Such a task can become taxing, hence any consideration should address layout and equipment. It is best to organize the training theatre in a simulacrum of the original which would greatly enhance and facilitate the learning experience (Mackway-Jones and Walker, 22-23).

2.4.3. Towards an Effective Training Environment

Ideally, professionals in their practice often seek a broad understanding and pay attention to developing their competence in the context of the fundamental purposes and values that underpin their work (De Cossart and Fish, 54). However, reality only allows for a small number of problems to be resolved by strictly using research-based methods and clinical application. In surgery the situation is comparable: few universally agreed upon solutions can function as an absolute, and hence, few universal and absolute solutions are available to accommodate current training difficulties in surgery (Richards, 12).

Moreover, the complexity of surgical situation is apparent; clinical studies, categories of applied sciences, theory, and professional views, will have different and often conflicting views on solutions and strategies needed. Still, all these views, especially ones coming from within the system should be measured and are important to consider and would contribute immensely to a solution. The obligation of a trainer surgeon is then to make sure that such views are neither suppressed nor circumvented and disclose concerns to be evaluated and eventually resolved. To that end, De Cossart and Fish suggest some new approaches to the education of surgeons. At the beginning they make distinction between educational theory of the classroom and skill development in clinical setting. That distinction, though crucial, seemed to suffer as their book progressed. Nevertheless, some of their suggestions are still valuable and considered below.

De Cossart and Fish recommend a wider range of activities in teaching and learning such as a learner-centered approach with learners taking responsibility for documenting the evidence of their development (17). While this approach could be of use to surgical trainees, still, an exaggeration of the evidence by the trainee could occur due to a conflict of interest–the trainee in such situation is effectively documenting their own evaluative evidence. De Cossart and Fish second recommendation is that by incorporating the use of reflective practice (discussed section 2.2.3) surgical trainee would enhance their understanding and draw wisdom from the experience gained. It is clear that theory is necessary for practice and the value of the opportunity of being critically reflective, in a training situation, would certainly increase the probability of generating viable theories. This paper made a point earlier in section 2.2.3 of the benefit of such an approach over others. Further still, new ways are needed to motivate

surgical trainees as well as aid the trainer to make obvious which operational procedures the surgical trainee has become successful in. As argued previously, simulation in this regard offers a great opportunity. Finally, Cossart and Fish note the importance of preparing the surgical trainee for entrance into a profession by preparing her/him to be a part of a larger community of practice, assessing all elements in the practice setting with a rigour and to let them to have an acceptable level of impact on the assessment process (17).

While some believe that surgical dexterity can only be assessed by a skilled and experienced observer (Richards, 12), research indicates that an effective use of simulation modules would assist a learning surgeon to arrive to an explicit recognition of professional values and skill associated with a particular procedure. Such an approach would, arguably, improve the probability of success when handling a real life situation. At least, a module such as this, as Hughes indicates, would be capable of demonstrating to the assessor, with some credibility, the level of competency of the surgical trainee.

> The ability to handle real trauma situations and learn procedures in a virtual world would be optimal for any new medical students. The students would be able to perform the required surgical tasks in a safe and non-threatening environment (80).

Such a device as the one argued for in this paper would arguably contribute positively to the development of an educationally sound training curriculum, and appropriate new approaches to teaching and assessing clinical settings. Clearly such a module could improve the performance of surgeons.

Chapter 3

The Module

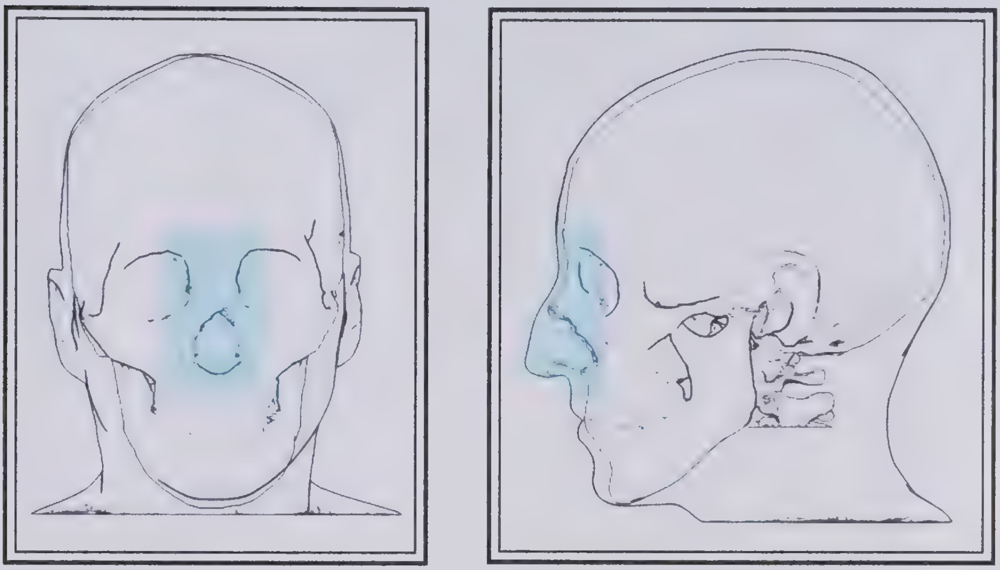
3.1. Introduction

The development/prototyping process described here is a demonstration of how to best create a rhinoplasty training module that focuses of standard rhinoplasty procedures including prominent dorsal hump condition. This chapter will elaborate the technicalities of creating such a module—data acquisition, data processing, construction of module components in CAD (computer aided drafting), construction of molds in CAD, rapid prototyping, mold preparation, cast material, and casting process. Additionally, this chapter lists a series of experiments and results, the materials used in casting and discuss their properties, processes used to manufacture the prototypes, discuss options for final molds production, and provide a list of manufacturers for production consideration. The methodology discussed here is specific for this module. It can, however be used as a guideline to enable the production of tools which focuses on other nose conditions.

3.2. Area of Interest

The area of interest for the module includes parts of the midface, the complete external region of the nose, and underlying substructures that directly relate to and influence the nose deformity

known as Prominent Dorsal Hump. The shaded rectangular areas in the figure 3.1 illustrates the area of interest; the superior border of the module starts at the level of the eyebrows, the inferior border is at the upper lip, the anterior starts at the tip of the nose, and posterior border of the module is at the turbinates.



A B

Fig. 3.1 Frontal profile of the area of interest (A). Side profile of the area of interest(B).

The following components are required to reproduce the scenario of a Prominent Dorsal Hump deformity:

1. Bone tissue.
2. Exterior skin.
3. Septal and upper lateral cartilage.
4. Lower lateral cartilages.

3.3. Data Acquisition

For reasons of balancing manufacturing feasibility with delivering a correct and useful training module, 'anatomical correctness' rather than 'anatomical accuracy' governed the process of data acquisition. Being faithful to the shapes and characteristics of the components rather than precisely duplicating the nose of the subject.

Three processes were examined for data acquisition: high-resolution digital images of human cadaver slices, MRI scans, and CT scans—as explained in the subsequent section.

3.3.1. Digital Images of Human Cadaver Slices

Using this method, the data would be acquired by slicing the head of a cadaver in thin cross-sectional cuts. Axial slices between 0.33mm-1mm (Van Pinxteren, Lohuis, Ingels, and Trenité, 329) are optimal. These slices are then photographed using a high-resolution digital colour camera. The two-dimensional images are then stacked to create a three-dimensional volume; using image processing software, such as Adobe® Illustrator® or Autodesk® Combustion®, structures of interest can be traced and extracted speartly from each image and the paths exported in DXF format. The DXF[1] format is recognized by most CAD programs, such as Autodesk® 3ds Max®, can be imported, stacked, attached, and welded to create a voluminous object that precisely represents the structure/area of interest.

Acquiring data using this method is considered to be the most accurate and reliable (Van Pinxteren et al., 329) but is time consuming and expensive. In consultation with Dr. Anil H. Walji, professor and

[1] The DXF™ format is a tagged data representation of all the information contained in an AutoCAD® drawing file.

director of Anatomy Division [2] at the University of Alberta, it was concluded that the scale and cost required for this approach is inappropriate for this study for the following reasons:

- The anatomy division at the university does not have the equipment to cut 0.33mm-1mm slices required for this project.
- An expert in cadaver preparation and slicing would need to dedicate a considerable amount of time to perform this task.
- A construction or modification of a dedicated station equipped with a high resolution camera would be needed for the task.
- Strict polices on transporting human cadavers; CT scans of the cadaver's head are needed before slicing; these would be used to construct the bone tissue.

Upon further research, it was found that human cadaver datasets are available commercially. The Complete Visible Human™ is a high-resolution anatomical datasets of male and female cadavers. The datasets are based upon the National Library of Medicine's (NLM) Visible Human Project™. The Virtual Nose Project of Dr. A. john Vartanian *et al.* used the NLM dataset to create a three-dimensional virtual reality model of the human nose (Van Pinxteren, Lohuis, Ingels, and Trenité, 329). While access to such datasets came at the late stage for this research to effectively employ them, it is recommended such datasets be considered for similar projects in the future.

---

[2] Dr Anil H Walji, Professor & Director of Anatomy Division, UofA, 5-05B, Medical Sciences Edmonton, AB Canada , T6G 2H7, Tel: (780) 492-8629, email: awalji@med.ualberta.ca

Fig. 3.2 Example of a cadaver slice from the National Library of Medicine's (NLM) Visible Human Project™

3.3.2. MRI Scans

Magnetic resonance imaging (MRI) was closely considered as well. The data was acquired from a subject using the DESS sequence which was recommended by a specialist in the field. This sequence is supposedly capable of imaging soft tissue with a better degree of resolution compared with other sequences. The sequence captured 128 slices with a thickness of 1mm for each slice. Tests were conducted on the images acquired using Mimics® (medical image processing software). The tests proved that the process to extract the structures of interest using the DESS sequence are impractical and the results unusable. Although the MRI images boasted better count of pixels, hence a higher resolution (Mimics® separates areas of interest

by defining a range of pixels on a gray scale[3]), the range of the gray scale in those images was narrow and dispersed throughout the slices which rendered Mimics® separation algorithms incapable of defining the structures of interest. Manual separation was examined as well and the results were similar.

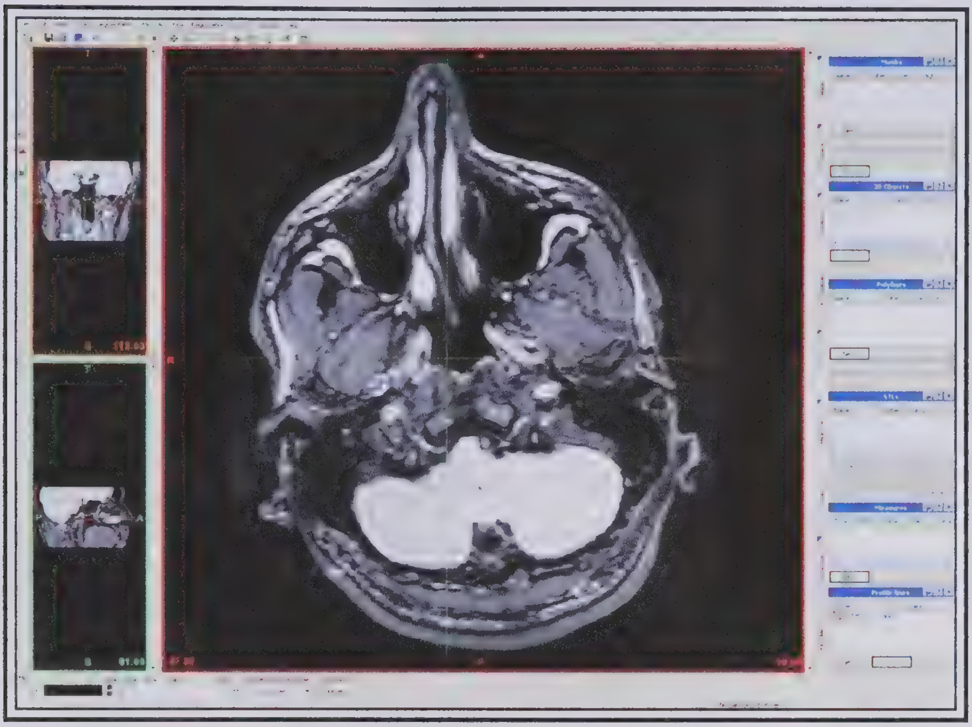


Fig. 3.3 An MRI image displayed in Mimics®

A combination of reasons can be attributed to such a result if only by assumption. For example the power of the magnet of the MRI machine used proved inadequate, the processing capabilities of Mimics® was inferior in dealing with MRI images, the software seems to be designed to deal in large with extracting bone tissue from CT (Computed Tomography) images rather soft tissue from MRI, and the DESS sequence is incapable of efficiently imaging cartilaginous tissue.

---

[3] Mimics® interactively read CT/MRI data in DICOM format. By manipulating Segmentation and editing tools, an area of interest can be isolated, and visualized in 3D. The data can be exported as STL, DXF, VRML, and other file formats, which can interface with a myriad of other CAD software. (Mimics tutorial, introduction, overview of mimics modules)

After careful revision of the results, this process was deemed inefficient.

3.3.3. CT Scans

Computed Tomography (CT) Scanning was the last process to be considered for data acquisition. Although, it was dismissed initially for the incapacity of CT scans to render high-resolution images of soft tissue, CT slices are capable of capturing bone tissue and sinus cavities with great detail and accuracy. The CT scan produced 301 slices with variable thickness increments. Tests were conducted on the images acquired using Mimics®.

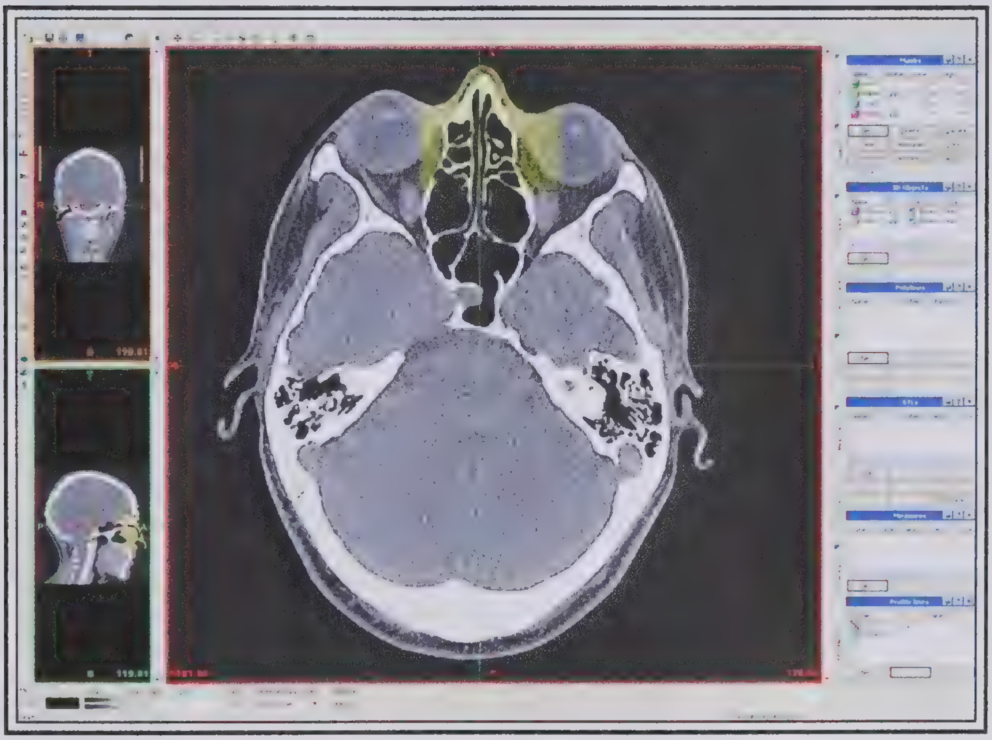


Fig. 3.4 CT image displayed in Mimics®; area of interest highlighted.

The tests proved the ability of acquiring bone tissue and skin tissue with great accuracy. As well, CT data of the sinuses, nasal passages, skin, and others, proved useful as a reference and a blue print for modeling the cartilaginous tissues needed. In considering the

scope and the goals of this project, some of the components would be completely derived from the CT scans such as the bone tissue and the skin tissue with minor modifications to accommodate and facilitate the production of the module. Meanwhile, for other parts to be realized, such as the cartilaginous tissue, more creative liberty had to be exercised. This interpretive process relied heavily on the data provided by the CT scan. It was crucial to exert great diligence and attention to the creation of these parts so as they would correspond with the components derived directly from the CT data, thus maintaining the integrity and the stated goals of the module.

3.4. Development Pipeline and Data Processing

Figure 3.5 illustrates the general pipeline scheme used to process acquired data to produce the discrete elements of the module. Each element was processed through this pipeline with slight variations. The following explains the steps included in the development pipeline:

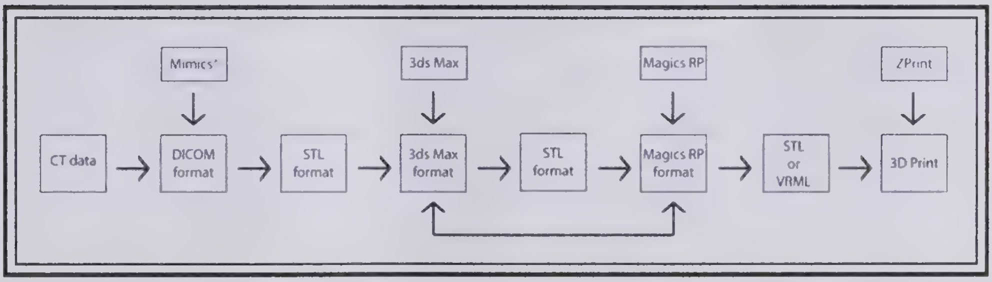


Fig. 3.5 General pipeline scheme used to process the CT Data

- Mimics® medical software is capable of reading medical imaging data such as MRI and CT. It was used to isolate individual structures that make up the area of interest; such as bone tissue and skin tissue.
- 3ds Max®, a powerful 3d editing tool, was used to modify STL files (stereolithography format) exported from Mimics®, as well as

modeling some elements of the module and modeling molds. It was the workhorse of the development pipeline.

- Magics RP® is a rapid manufacturing software. It was used to repair 3d models exported from 3ds Max®, prepare the 3d volume for rapid prototyping and be definitive about it integrity. The software was also capable of creating a myriad of object and manufacturing reports that was useful for development purposes.
- ZPrint® is software that interfaces CAD files with the rapid prototyping machine and it is native to the machine.
- Zcorp Spectrum Z510 3d printing machine is a "...solid freeform fabrication (SFF) or layered manufacturing technology. Powdered material are deposited in layers and selectively joined with binder from an ink-jet printhead" (Lanzetta and Sachs, 157).

3.4.1. Converting CT Data to CAD Files

This step is concerned with converting the grey scale, two-dimensional CT images to voluminous three-dimensional CAD files. While there are other options available for this project this step took place in Mimics®. The process in Mimics® consisted of importing the CT data, isolating the area of interest, exporting bone and skin tissue, and creating reference data for the modeling of other elements. Importing CT data into Mimics® is rather a simple procedure[4]. By means of creating layers and using available tools, the CT images can be manipulated in order to isolate structures of interest. It was determined that the axial area of interest for the module lies between 65.56 and 146.92, the coronal between 177.84 and 233.06, and the sagittal between 100.62 and 145.08. To isolate this area, the entire scan was highlighted by using the threshold tool.

---

[4] Many of the steps described in this segment are detailed in the tutorials section of Mimics® help menu.

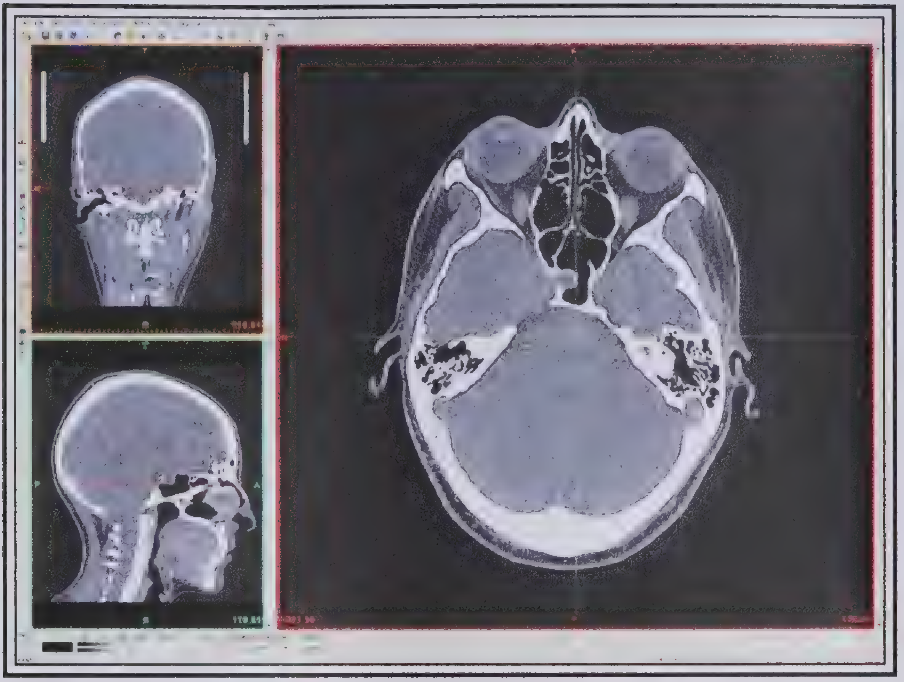


Fig. 3.6 CT Data imported to Mimics®.

Once the data was highlighted slices at the previously indicated positions were deleted isolating the area of interest—see Fig. 3.7.

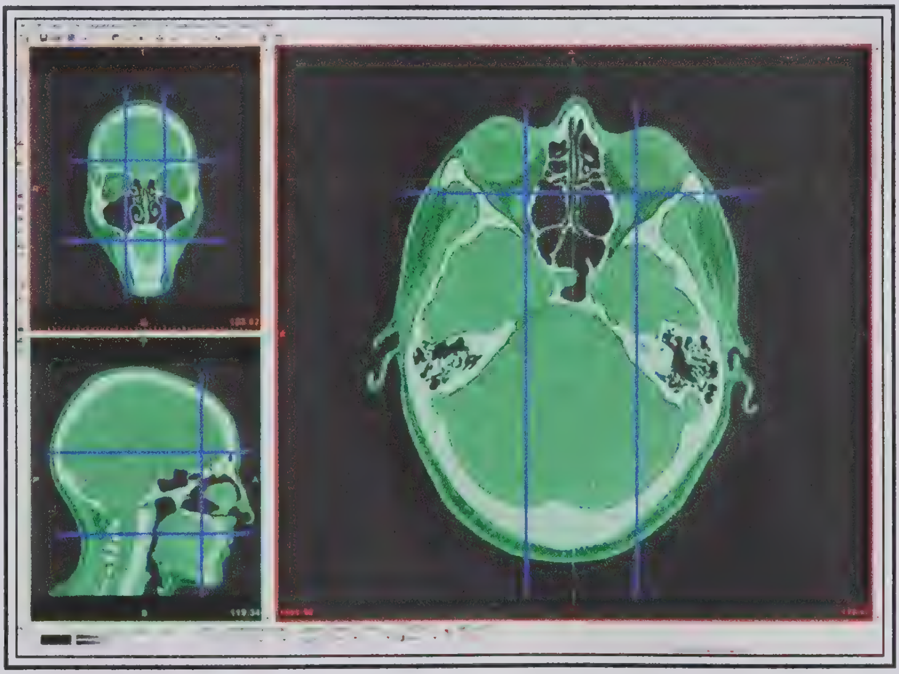


Fig. 3.7 The scan is highlighted using threshold tool—the green area. Slices deleted to isolate the area of interest—the blue lines.

The same process of thresholding was performed although was best done as a 'selected threshold', to isolate skin and bone tissue, Fig. 3.8, and create the 3d objects and the STL files, Fig. 3.9.[5] Furthermore, as shown in Fig. 3.11, the area of interest is exported in its entirety as an STL file to be used as a reference when creating other module components— the cartilaginous tissue. It should be noted here that a great effort was attempted to extract the cartilaginous tissue by studying anatomical references and then attempting to threshold the structures manually. Due to inadequate resolution levels of cartilaginous tissue in the CT slices, the resulting 3d structures did not reach desired results.

Fig. 3.8 Bone tissue isolated—the purple area.

[5] The extraction steps are explained in detail in the tutorials section of Mimics® help menu.

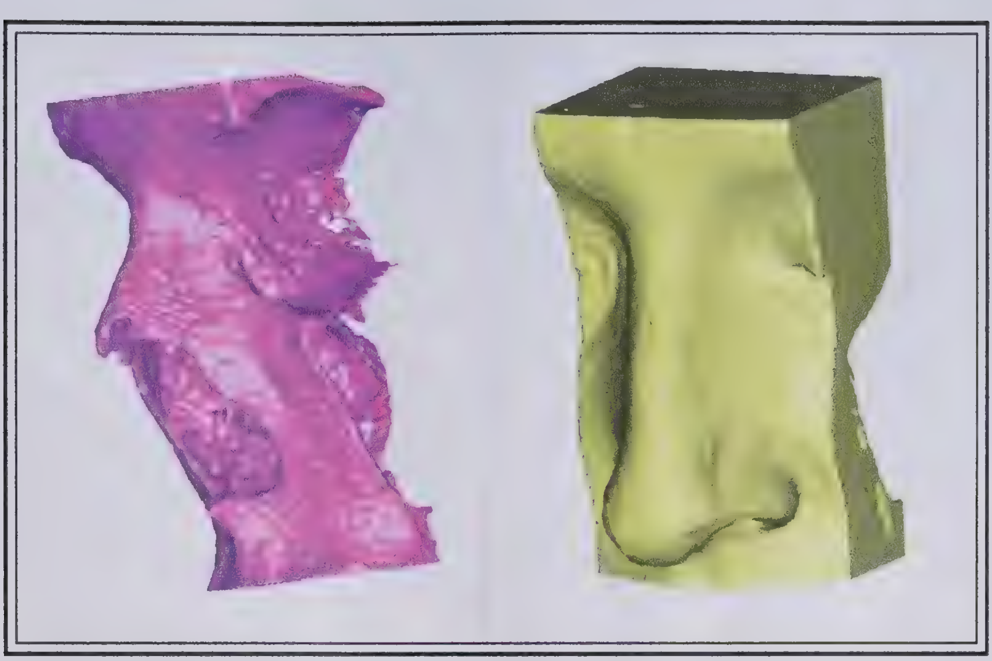


Fig. 3.9 Three-dimensional view of the bone and skin tissue visualized in Mimics®. Note the coarse quality of the surface, noise and artifacts.

Fig. 3.10 The area of interest isolated— the yellow area.

Since Mimics® creates the voluminous STL files by interpreting the grey scale value of the CT images (this is why it is predominantly used to isolate bone tissue; bone has a notable level of contrast when compared to other tissues), the side effect to this process is that 3d models being extracted would have a level of "noise" and artifacts associated with them, see Fig. 3.9. This issue is addressed and resolved in the subsequent section.

3.4.2. Processing the STL Files

This step is concerned with correcting the 3d volumes exported from Mimics®, creating 3d models; this step uses data from mimics only as a reference, and finally creating molds that are capable of recreating the module components. While there is a myriad of 3d packages on the market that are capable of doing the work described in this section, 3ds Max® was the program of choice for this project because of my capability to use this program. Each component of the module was managed somewhat differently and the open ended nature of this 3d program allows for several possible solutions, hence each discrete component of the module will be discussed separately in this chapter.

3.4.2.1. Bone Tissue

The processing of the bone tissue was a simple event and was a result of a straightforward application of the development pipeline (Fig. 3.5). The fact that CT scans are best for detecting bone tissue and Mimics® architecture revolves around the same trait are both reasons for such outcome. Figure 3.11 shows the amendments the 3d model went through in 3ds Max®; these amendments which were carried out for manufacturing necessities were conducted with approval from the supervising surgeon.

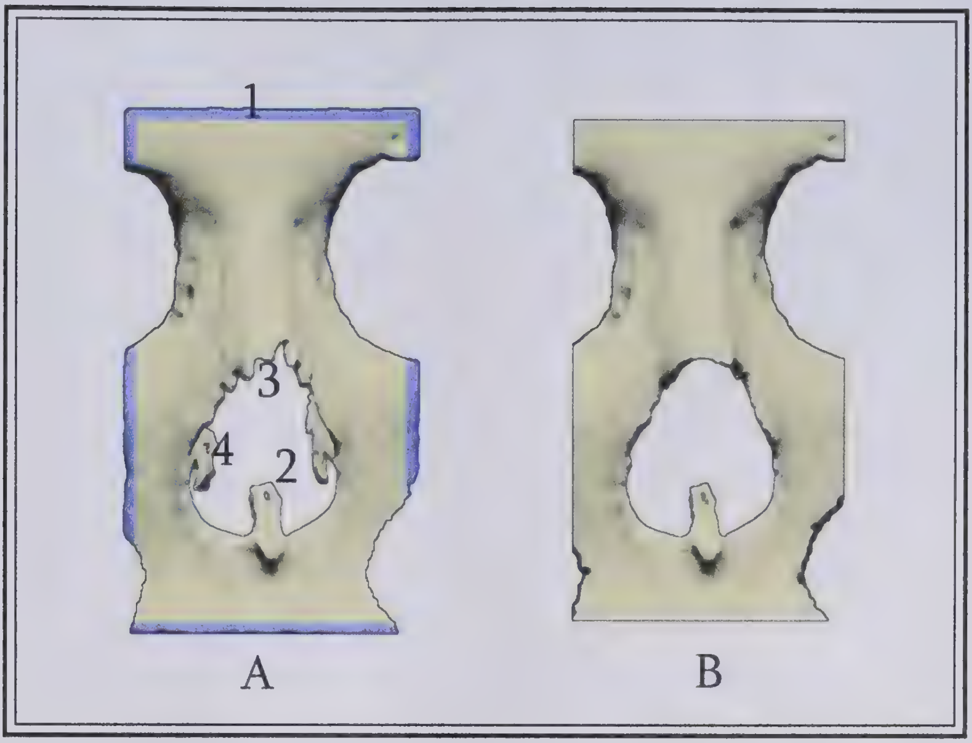


Fig. 3.11 Part A is a front view of the bone tissue imported from Mimics®. Part B is the same tissue after modifications.

Part A is the bone tissue part imported from Mimics®. Its dimensions are 82mm x 31mm x 46mm. A straight cut (See A in Fig. 3.11.) was made around the entire part (See 1 in Fig. 3.11.) eliminating unnecessary noise to make the borders uniform. The dimensions after the cut are 72 mm x 31mm x 42mm. The posterior of the premaxillary table (See 2 in Fig. 3.11) was slightly trimmed, and the inferior turbinates (See in 4 Fig. 3.11) were removed, to allow easier insertion and extraction of the nasal passage molds during casting. The severe irregularities in the nasal bone (See 3 Fig. 3.11) were tempered on the request of the supervising surgeon. In this case, the bone specimen showed irregularities uncommon on such scale that could interfere with objectives of this module.

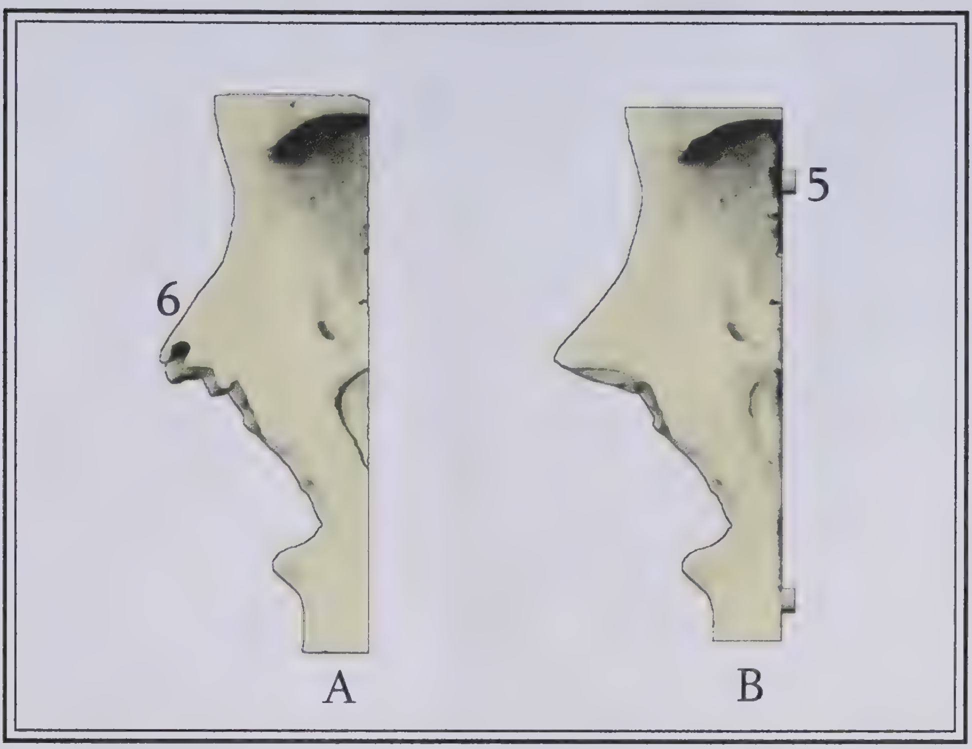


Fig. 3.12 Part A is a side view of the bone tissue imported from Mimics® Part B is the same tissue after modifications.

As shown, the nasal bone was also slightly extruded (See 3 Fig. 3.12) on the request of the supervising surgeon in order to make the Dorsal Hump condition more prominent in the module. Two anchors were added to the back of the part to prevent it from moving while casting as that area would be of little interest for the trainee. After adding the anchors the dimensions of the part became 72 mm x 35mm x 42mm[6]. The final step in 3ds Max® was treating the mesh with local smoothing and tessellation algorithms to heighten the face/polygon count and hence the quality of the surface without affecting the overall shape.

[6] It should be noted here that the frequent change of measurements was a consequence of deliberations and experimentation between the members of the development team. The author took the decision initially to expand the area of interest and later reduce/change it by eliminating the undesired sections by deleting faces/polygons rather than going back to the previous stage to export another set of modified data; hence saving time and effort. This justification applies to other size reductions that took place in later stages in the process.

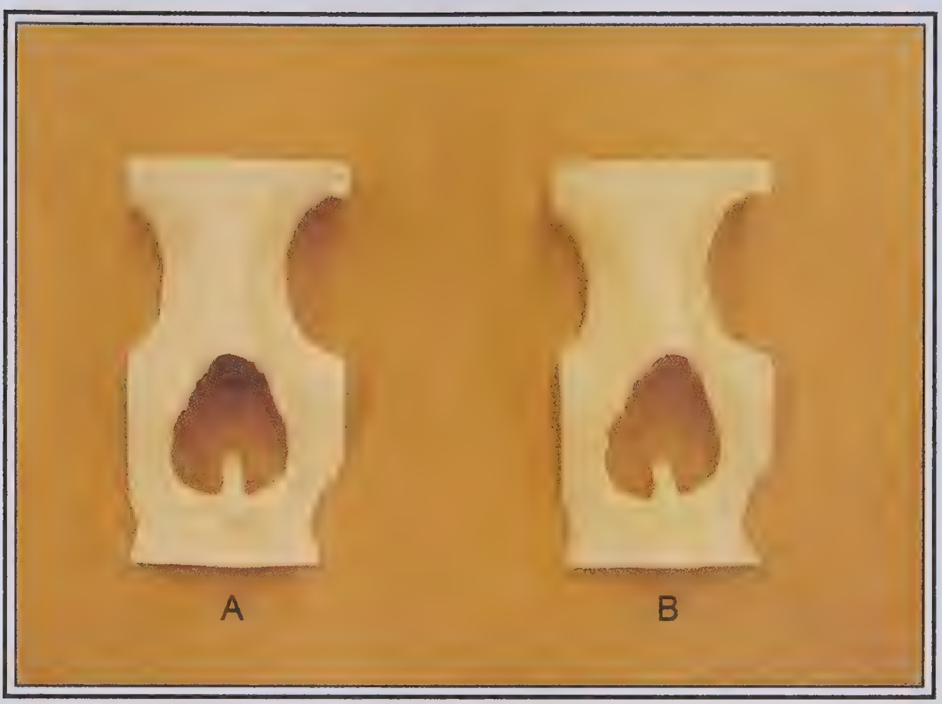


Fig. 3.13 Bone tissue part in 3DP: Zcorp® 3DP (A), FMD 8000 (B).

Imported into Magics RP the part is checked for structural integrity and repaired accordingly; a mesh should not have any inverted normals, bad edges, bad contours, planar holes, shell noise; otherwise the 3D printer will not accept the file. Moreover, while overlapping intersecting triangles do not affect the process of 3DP, it is best that they don't occur in the mesh. The part is then Prototyped using the Zcorp® 3DP, then treated with several coats of Crystal Clear Acrylic®, each coat left to cure overnight, the acrylic coats allowed the silicon to cure and to loosely adhere to the 3DP. Still, the prototype was brittle and could not withstand the osteotomy procedure. In later stages of development the Zcorp® 3DP was replaced with and ABS plastic prototype produced by FMD 8000 (C ideas) so as to facilitate osteotomy procedure when the module was tested for performance.

3.4.2.2. Skin Tissue

The processing of the skin tissue was similar to the bone tissue. However, the difference lies in the extensive amount of noise and superfluous data that was associated with the skin. It is possible to isolate the skin using Mimics®, however the process would be quite complicated due to adjoining soft tissue with comparable gray scale variations. Alternatively, to threshold the complete area of interest in Mimics® (See Fig. 3.10) and export it as an STL file, and then eliminate the noise and the excess data manually using 3ds Max® (See Fig. 3.14), would consume less time and yield superior mesh quality. The mesh surface was further simplified using MultiRes algorithm in 3ds Max® to allow further manual editing and extraction of specific areas of importance[7].

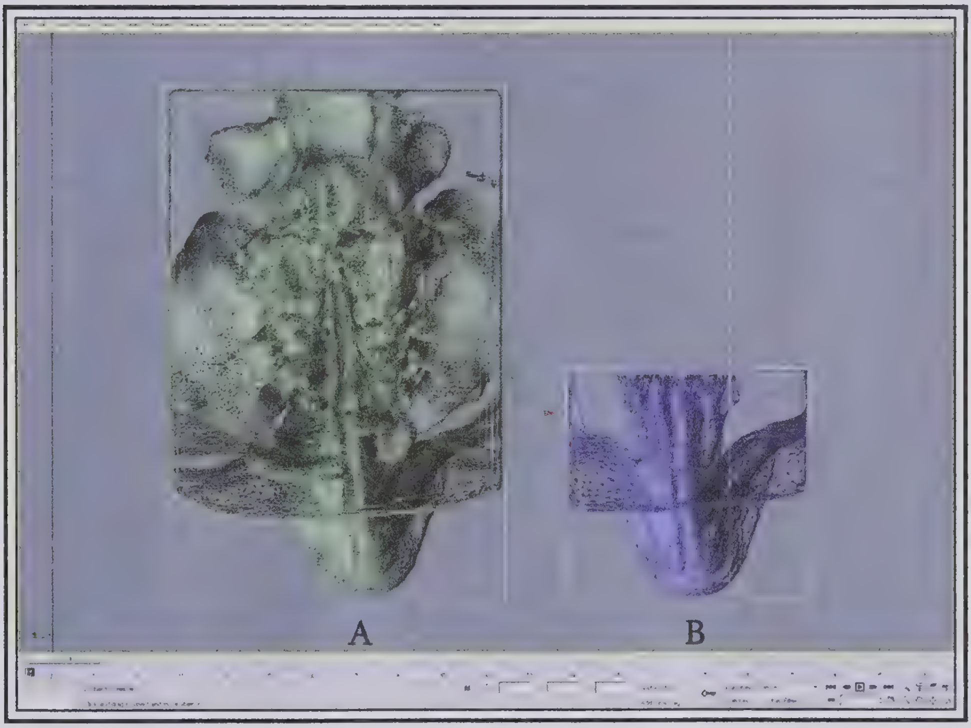


Fig. 3.14 The whole area of interest imported from Mimics® to 3ds Max®, note the internal substructures (**A**). The skin and the nasal passages isolated (**B**).

[7] See septal and upper cartilage in section 3.4.2.3 and lower lateral cartilage in section 3.4.2.4.

The boundaries of this part (part B) ultimately serve as the outer boundaries of the module. Figure 3.15 illustrates the modifications that were conducted on this part; the original part imported from Mimics® measured 98mm x 98mm x 64mm. After the unwanted mesh excess (area 1 highlighted in purple in figure 3.15), the new area measured 44mm x 82mm x 46mm. This would approximate the size of the training module. The mesh surface was treated with local smoothing and tessellation algorithms to heighten the face/polygon count, to improve the quality of the surface (See 2 in Fig. 3.15). Once the nasal bone was modified to pronounce the Dorsal Hump condition in the module, the skin tissue had to undergo similar modifications (See 3 in Fig. 3.16). The nose tip area was modified to accommodate the modifications in the nasal bone (See 4 in Fig. 3.16). All the indicated modifications were requested and approved by the supervising surgeon.

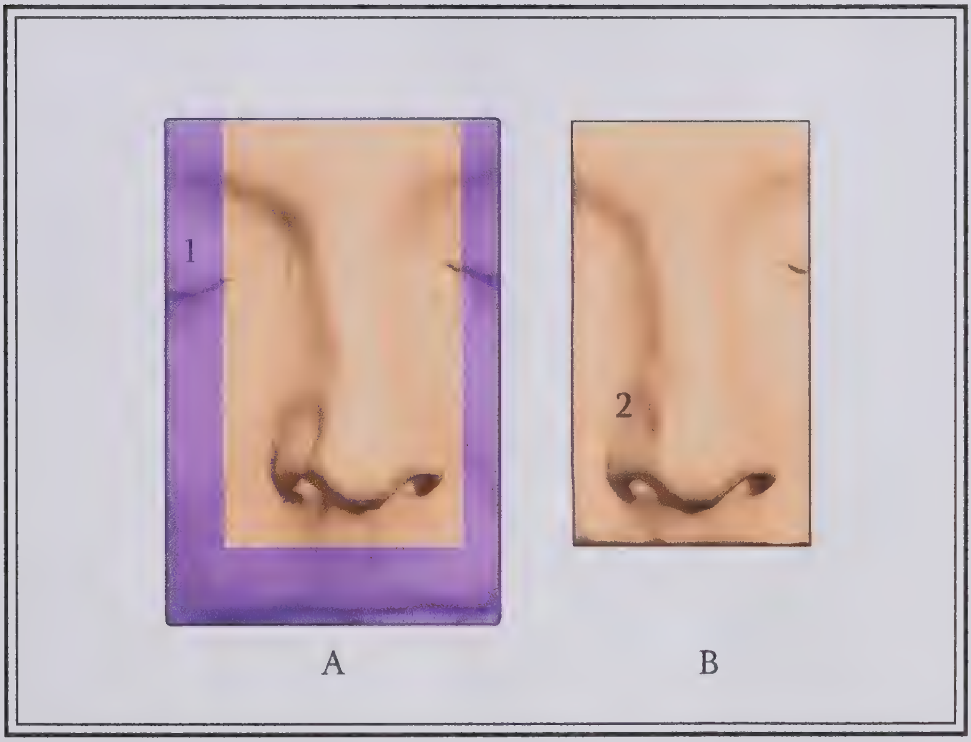


Fig. 3.15 Front view of the original and the modified skin tissue

One of the most challenging aspects of this module was the need to cast the skin (exterior) along with the nasal passage (interior, See 5 in Fig 3.16) without creating anatomical errors such as a noticeable laddering effect which could possibly peel off when the module is in use or creating a casting ridge that might loosen and renders the module inoperable. Consequently, it was necessary that both the skin and the nasal passages be cast simultaneously.

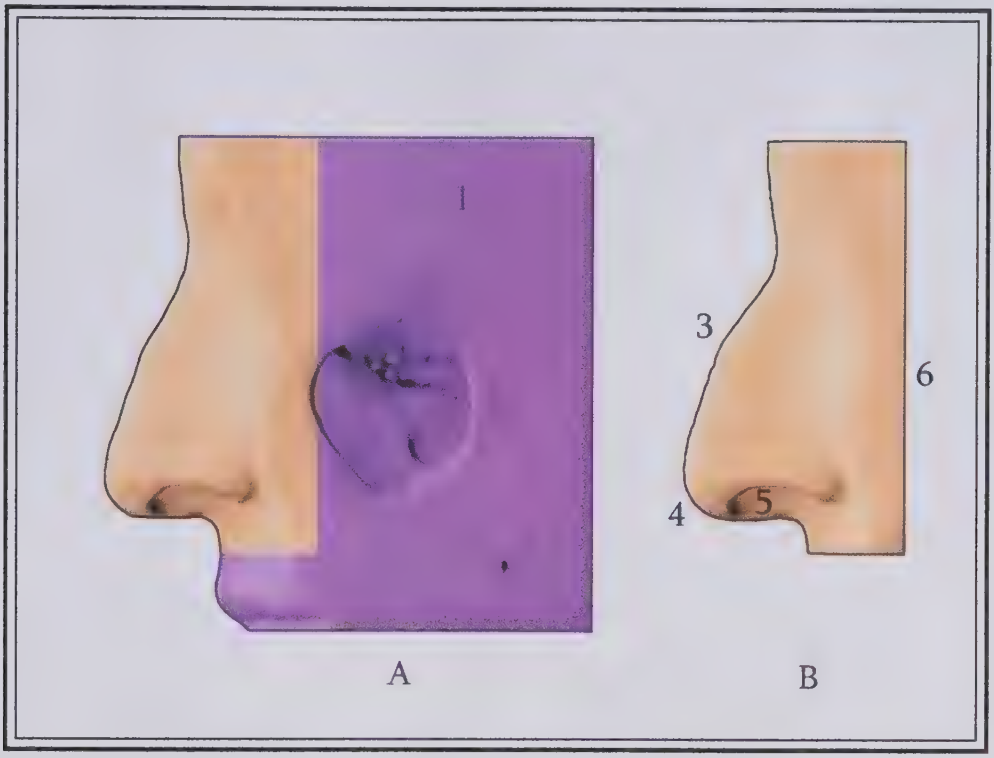


Fig. 3.16 Side view of the original and the modified skin tissue

3.4.2.3. The Septal and the Upper Lateral Cartilage

As explained in earlier sections, adequate data of cartilaginous tissues were not available. Therefore, the septal and the upper lateral cartilage had to be modeled entirely in CAD. 3ds Max® was used for that purpose. While this process mainly relied on knowledge and experience with the modeling tools in 3ds Max®, some data was useful as blueprint—the skin part discussed earlier and the mesh shown in

Fig. 3.14 A. The first attempt utilized the guides available from the converted[8] CT data to construct the septal and the upper lateral cartilage within its confines. The results, however, were less than convincing as the mesh had a distinctive feel to it of being constructed in a CAD program. That 'fake' hint would certainly compromise the overall realistic appearance desired for the module. This approach was abandoned. The next attempt resorted to extract surfaces from the available meshes derived from the CT data, especially the surface skin since the shape of the nose is largely depended on shape of the cartilaginous tissue. This process proved successful withstanding all the tedious steps necessary to extract and modify the surfaces. Accordingly, the upper lateral cartilage was extracted from the skin, Fig 3.17, and the septum was derived from the nasal walls and those joined together and amended accordingly with a variety of modeling tools to arrive at a suitable septal and upper lateral cartilage, Fig 3.18.

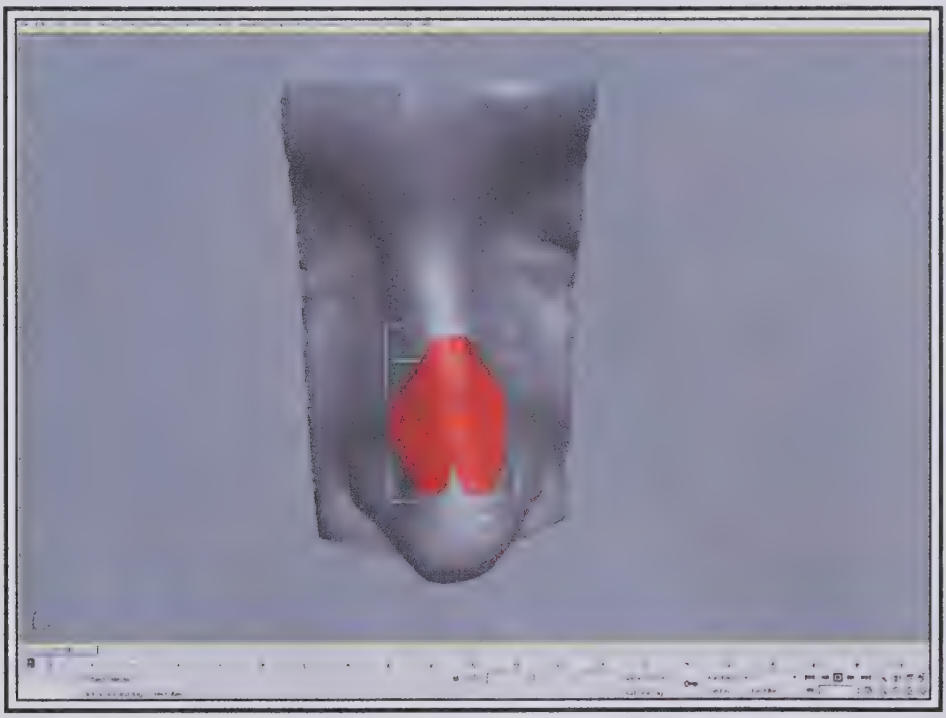


Fig 3.17 The triangular cartilage of the upper lateral cartilage being extracted from the skin part.

[8] The CT data converted to STL format and processed in 3ds Max®.

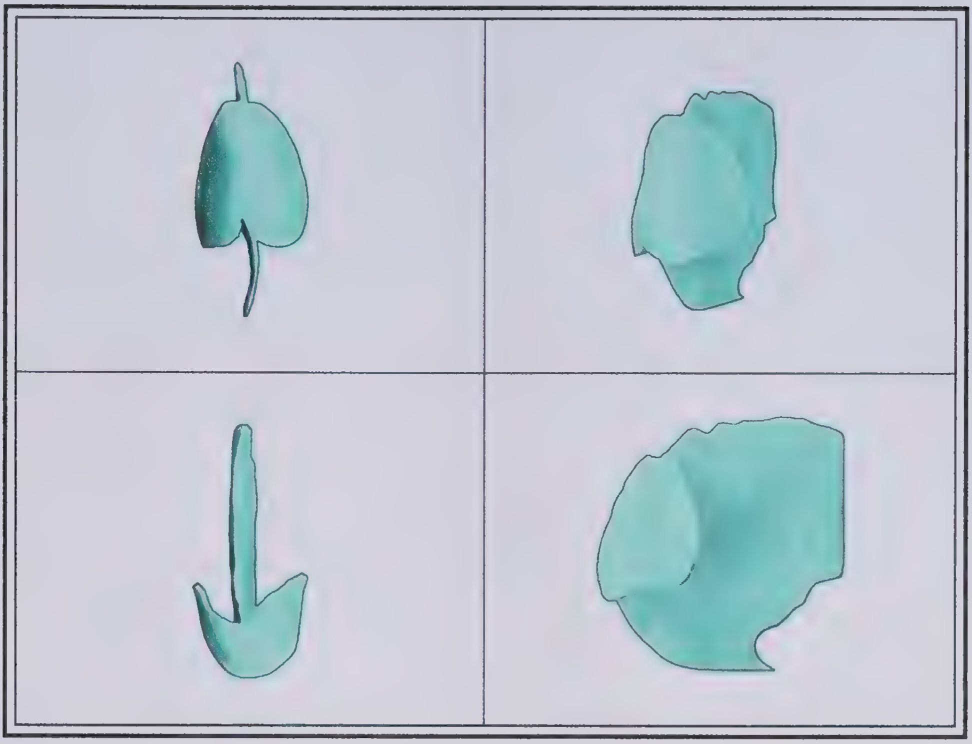


Fig 3.18 Septal and upper lateral cartilage part modeled, different points of view.

3.4.2.4. The Lower Lateral Cartilages

The lower lateral cartilages had an identical development approach and both had processing similarities with the septal and the upper lateral cartilage in that they as well were extracted from the skin part. Both cartilages were modeled separately and there was no mirroring of one to substitute the other in the interest of maintaining 'anatomical correctness' and circumvent cumulative future complications. The lateral crus, dome and intermediate crus where extracted from area between the nose tip and the alarfacial groove while the medial crus was extracted from the inside of the alar rim and part of the nostril wall, Fig 3.19. The two resulting pieces were joined together and amended accordingly with a variety of modeling tools to arrive at an acceptable lower lateral cartilage part, Fig 3.20.

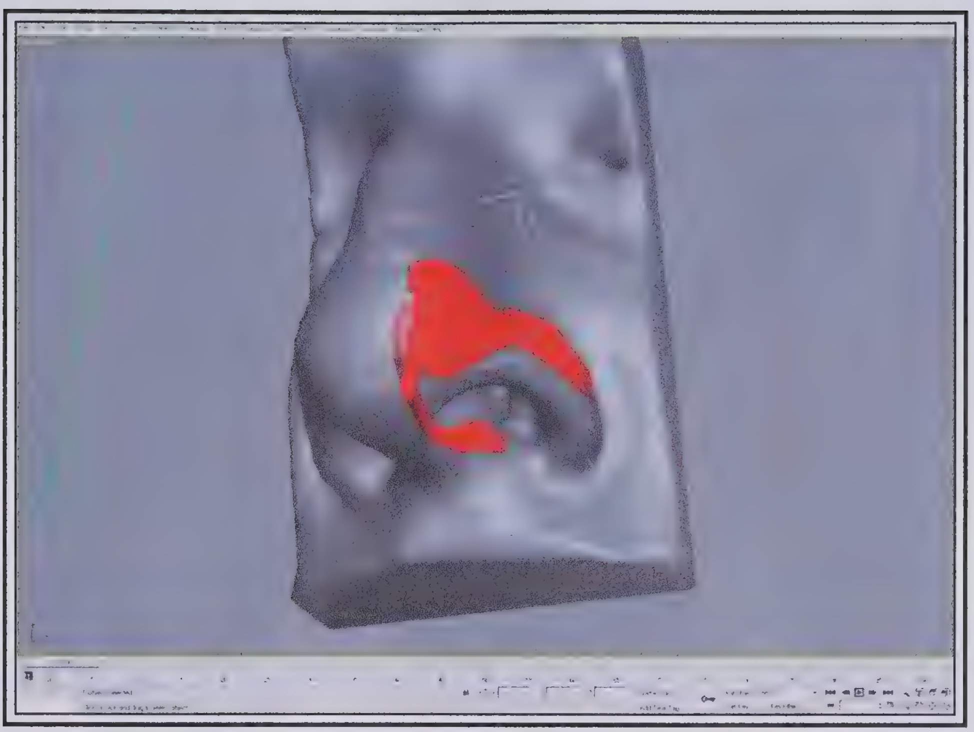


Fig 3.19 The areas extracted to create the left lower lateral cartilage.

Once the first draft of all parts had been created, a copy was submitted to the supervising surgeon. There was consensus that the results were sufficiently accurate, with only minor modifications need. With this encouragement, I was advised to advance to the mold stage of the design of the training module.

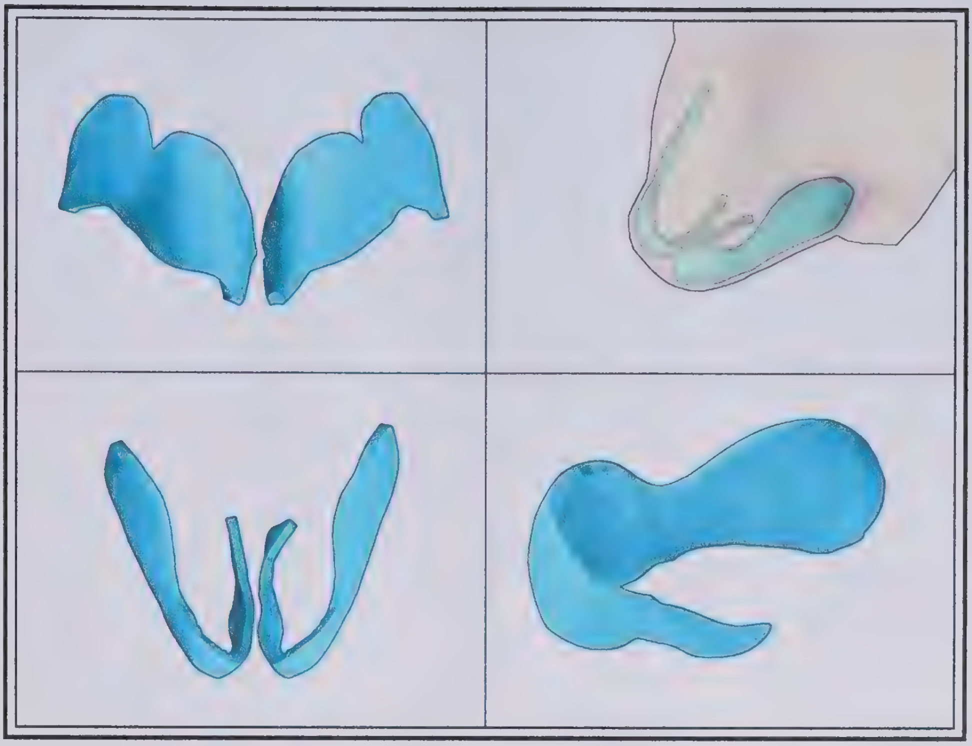


Fig 3.20 The lower lateral cartilages (except for bottom right; left cartilage side view), different points of view.

3.4.3. Making a Mold for Resulting Parts

The concept that governed the manner the design of the mold was that the cartilaginous tissues would be cast separately and the bone tissue manufactured using 3DP technology. Subsequently, these components (the cartilaginous and bone tissue) would be collected in a main mold, which would cast the rest of the module (skin, nasal passages, and subcutaneous tissue). This concept went through several iterations during the initial development phase and are described in the following sections.

3.4.3.1. The Mold: First Iteration

The molds for the cartilaginous tissue consisted of a simple two-part mold. Illustrated in figure 3.21; 1 and 3 are the lower lateral cartilages molds, 2 is the septal and the upper lateral cartilage mold.

The main mold was more complex and consisted of five parts illustrated in figure 3.22; 1 is the lower part of the mold, where the anchors (4) for the nasal passage parts (3) are situated. Once all the cartilaginous tissues were cast they would be introduced into the main mold. The lower parts of the main mold (1 and 2) would create the container in which the silicon, that makes the skin and the subcutaneous tissues, would be introduced. Following this they would be covered with part 5, clamped and baked in oven. The assumption with this design was that the silicon used to cast the cartilaginous tissue can be made fluid with a thinning agent that it could be injected into the crevices that constitute the cartilage shape and, after curing, it would be pulled out with tweezers since the silicone is flexible enough to stretch and not break. Both assumptions were too ambitious as the cast trial proved that to be the case (see Documentation of the Module's Casting Process in appendix E on DVD). Also, the reverse mold proved to be too difficult to handle during casting and the idea of introducing component in reverse fashion was confirmed as inefficient. As a result this approach was abandoned for a progressive mold approach.

3.4.3.2. The Mold: Second Iteration

The approach was first to try to limit a mold to three parts, in which organic shapes and the complex curves of the components would dictate the shape of the supporting walls of a mold. The walls would follow similar curves of the item being cast. Once reduced to its basic shape, a basic mold concept was developed. The septal and upper lateral cartilage, for example, resembles an arrow with four distinct surfaces as shown if figure 3.23. Once that concept was established, the model of the septal and upper lateral cartilage had to be divided into three corresponding sections. Each section was used

as a starting point for a mold-part, and its structure was directly derived from the section as shown in Figure 3.24.

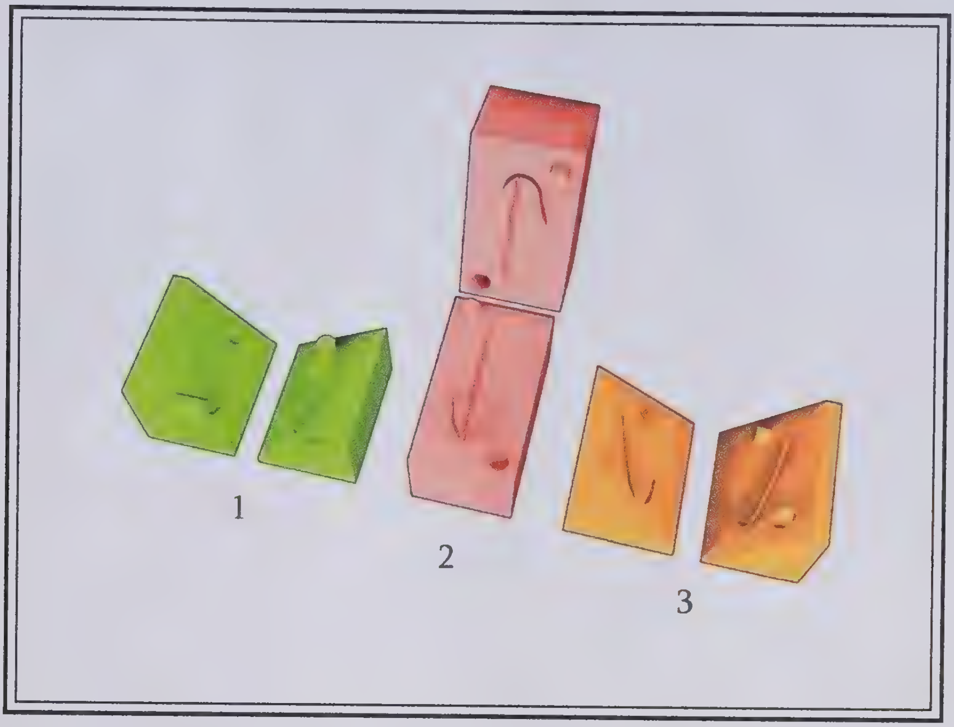


Fig 3.21 The first iteration molds to cast the cartilages tissue.

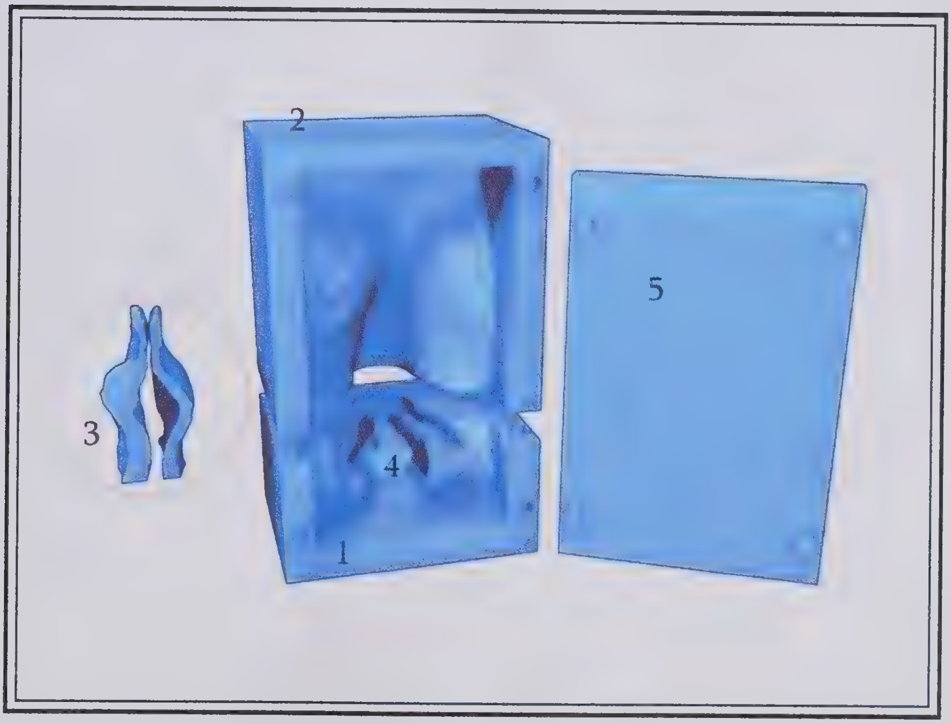


Fig 3.22 The first iteration of the main mold.

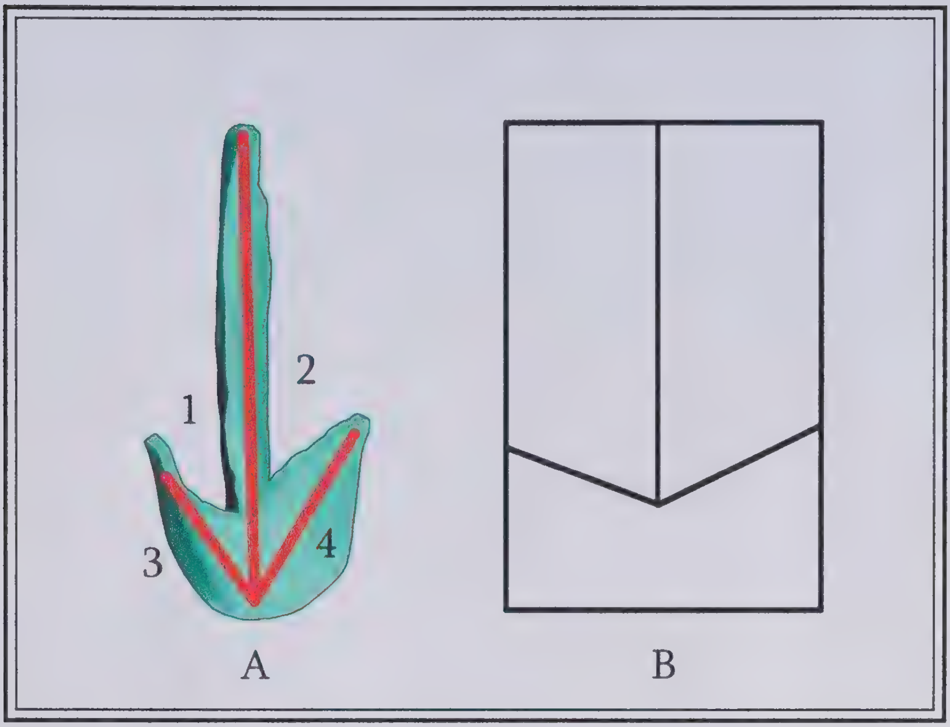


Fig 3.23 The four basic surfaces of the septal and upper lateral cartilage (A), the basic blue print of the mold derived from the arrow shape (B).

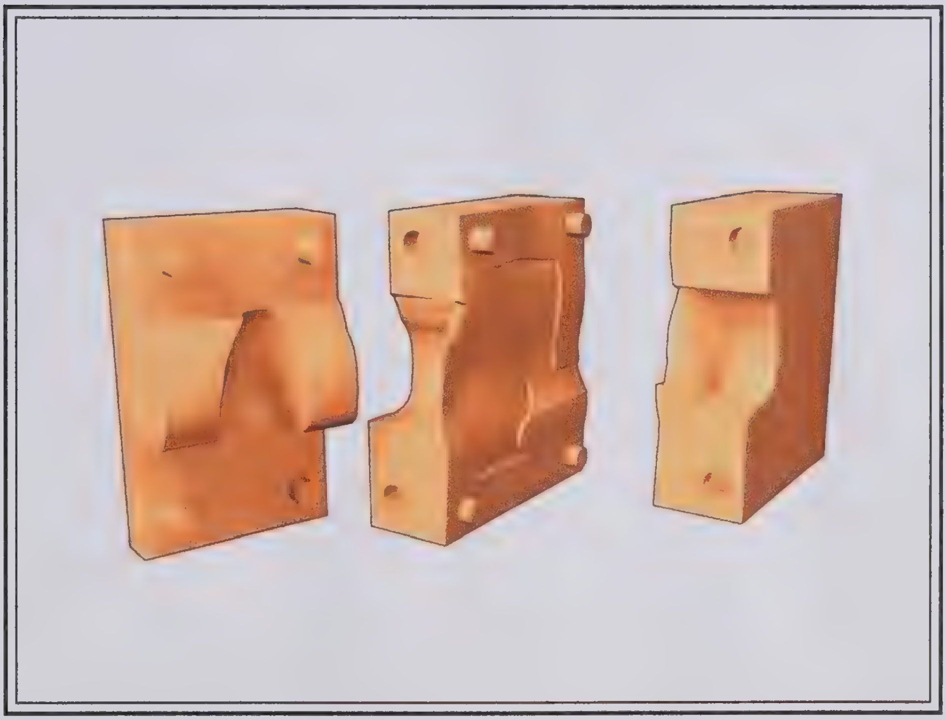


Fig 3.24 The three-part mold for the septal and upper lateral cartilage.

The same approach was followed with the lower lateral cartilages. The complex surface was reduced to its basic shape, a 'U' shape with three planes. Figure 3.25 illustrates the basic shape and planes, and figure 3.26 shows the resulting three-part mold. It should be noted here that even though figure 3.25 only illustrates the right lower lateral cartilage, the same procedure was applied for the left lower lateral cartilage.

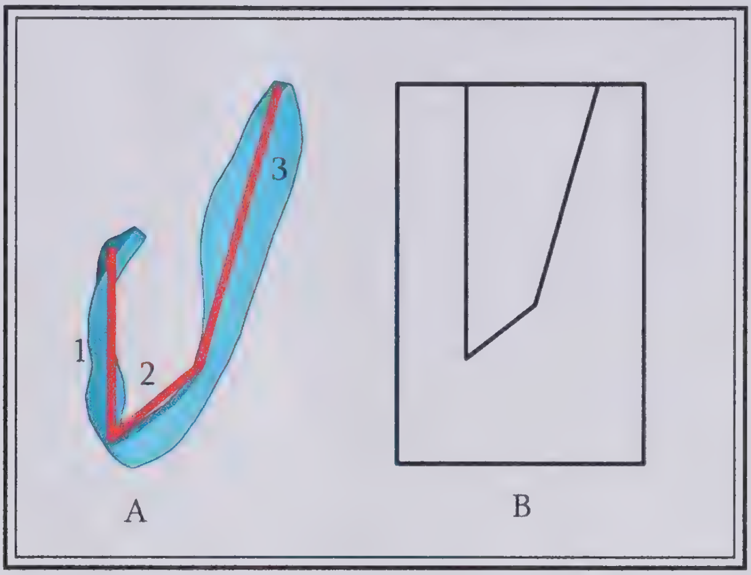


Fig 3.25 The four basic surfaces of the right lower lateral cartilage (A), the basic blue print of the mold derived from the 'U' shape (B).

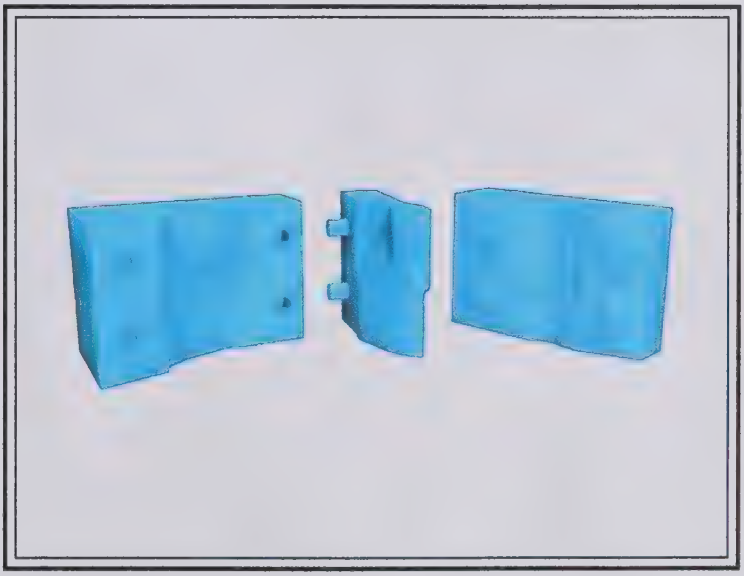


Fig 3.26 The mold for the right lower lateral cartilage.

Since the main mold design has evolved to a progressive mold from the reverse mold of the first iteration, one of the most obvious alterations from the first iteration was that the number of parts that make the main mold increased from five to six by introducing an access hatch at the bottom of the base of the mold in the second iteration. The nasal passage parts have evolved in this iteration as well since the anchor positions in the first iteration did not work—it was impossible to release the nasal passage parts from the mold without destroying them (See Fig. 3.22). With that in mind, the anchor positions were moved to a lower and more strategic section to facilitate removal after casting. As with the other molds in this iteration, the main mold used the curves and the surfaces of the skin model as the starting point to create the components of the mold (See Fig. 3.27).

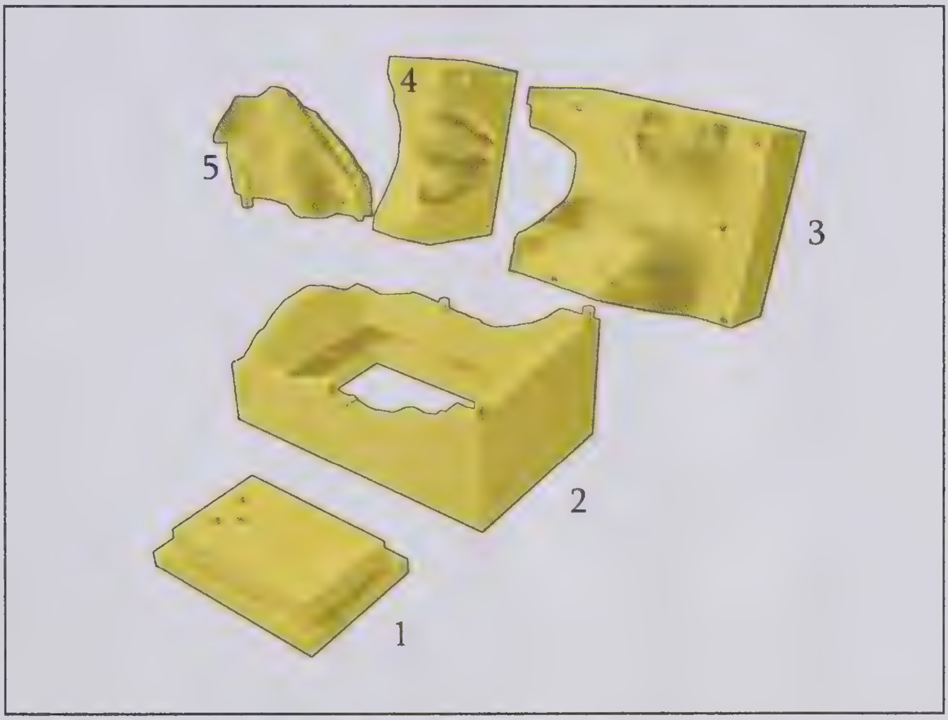


Fig. 3.27 The resulting six-part main mold. The bottom access hatch (1), base of the mold (2), top of the mold (3), top part of mold and anchor for the nasal passage parts (4), nasal passage parts (5)

The casting trial was successful with some minor adjustment needed for the main mold to improve on the result and minimize the labour required to cast the module. As for the cartilaginous tissue molds, the approval and the satisfaction of the supervising surgeon has amplified the entirely successful results achieved.

3.4.3.3. The Mold: Third and Fourth Iterations

Since the preliminary casts were successful with the second iteration designs, the third and fourth iterations consisted of further fine-tuning of molds to improve quality and reduce labor. The third iteration consisted of repositioning or redesigning of anchors, injection and vent locations, creating more space to work with when introducing components into the mold, and making the mold walls thicker to test the theory of thicker walls make for a stronger mold; Fig. 3.28 illustrates the indicated changes noted above:

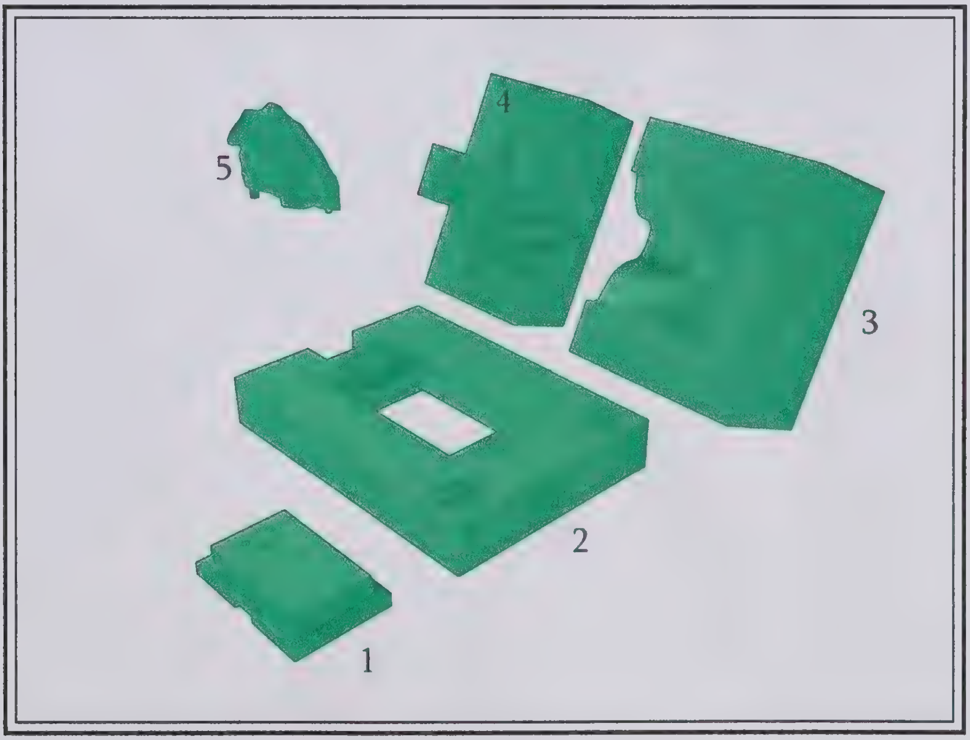


Fig. 3.28 The Modified main mold, 3rd iteration. Bottom access hatch (1), base of the mold (2), first top of the mold (3), second top of mold with anchors for the nasal passage parts (4), nasal passage parts (5)

For the fourth iteration, the thickness of the walls was reduced since the iteration three trials proved wall thickness to be inconsequential. The access hatch was eliminated and the number of components of the main mold was reduced to five components. Improvements in the design of the hatch offered to process were minimal in the previous trials. This module was cast twice using this iteration; both trials yielded constant and successful results. It is presumed that a prototype such as this can produce an upward of eight molds before the humidity eventually penetrates the protective barriers and spoil the plaster of the mold rendering it unusable.

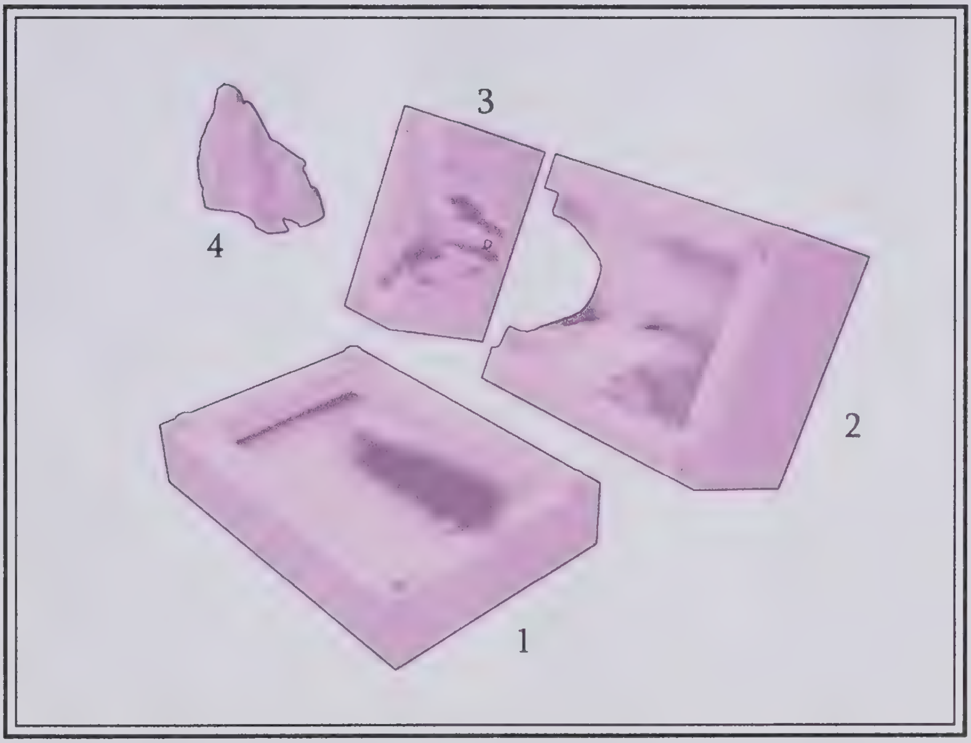


Fig. 3.29 The modified main mold, 4^{th} iteration. Base of the mold (1), first top of the mold (2), second top of mold with anchors for the nasal passage parts (3), nasal passage parts (4)

3.5. The Materials

- High performance composite material for prototyping module components and molds: This material used in the Zcorp 3DP process is a heavily engineered plaster material with numerous additives; this material can only be purchased form Zcorp and it is specific for use in their 3DP machinery.

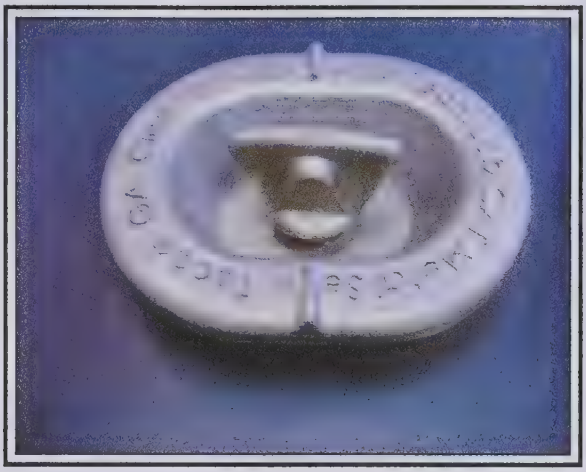
- Silicon for module components: for the cartilaginous tissues, FX-304 silicon putty was used. It is a heavy body impression putty two part 1:1, A:B. RTV platinum cure at 77°F approximately 5 minutes. It can be kneaded by hand and worked into a mold to create the parts ("Catalog/specialty" Factor II Inc.). As for the rest of the module, LSR Liquid Silicone Rubber was used. A two part 1:1 A:B. Platinum Cured, Translucent, Low viscosity, and have a cure duration in room temperature of approximately 3 hours. It is a low durometer silicone material that has a wide range of uses—Durometer: Shore A, 5 Tensile: 495, Tear: 70, Elongation % 990 ("Catalog/platinum" Factor II Inc.).

- ABS plastic for bone tissue: This material is used in the FDM8000 3DP process developed by 'C Ideas®'. ABS FDM models are structurally strong and responsive to carving.

- Copper or Aluminum for production molds: In consultation with Clemson Engineering Technologies Laboratory[9], these production molds can be manufactured by using either Z-Cast or resin bonded sand method. Cost estimation, based on personal correspondence is around USD 1200 in Feb 2006[10].

---

[9] Personal correspondence (check appendix A). Also check http://www.cetl.org/
[10] Check appendix A for a list of manufacturers offering similar services.



A

B

Fig. 3.30 Aluminum cast sample using resin bonded sand (A) and Z-Cast methods (B)[11].

3.5.1. Tests conducted on Mold Prototyping Materials

Initially, tests were performed to find appropriate material to strengthen the 3d prints (prototyping material) structurally to withstand 70 C° of heat and a maximum pressure of 1 bar/100,000 Pa. Most structure strengthening solutions use sulpher compounds as part of their make up; which inhibits the curing process of the silicon.

[11] Personal correspondence (check appendix A). Also check http://www.cetl.org/

Consequently, appropriate barrier material was needed to prevent inhibition by contamination.

As for heat resistance and structural integrity under pressure, two solutions were considered; CA20 Ethyl, manufactured by Adhesives Canada Inc., and Z-Max epoxy, manufactured by Z Corporation—both are Cyanoacrylate adhesive; sulpher-containing hardeners. 3DP plaster specimens treated with these solutions where exposed to sustained pressure, 1 bar/100,000 Pa over five hours period, and heat; 70 C° for 15 hours. While Z-Max epoxy was too viscous to allow for deep penetration levels of the 3DP plaster specimen. Still, Z-Max epoxy performed better than the more soluble CA20 Ethyl, which had a deeper penetration. When exposed to general and gradual pressure, both specimens performed equally well. When exposed to local pressure (from clamps), the specimen treated with CA20 Ethyl failed more quickly and seemed to be more brittle compared with the specimen treated with Z-Max epoxy. The table illustrated below summarizes the results:

Table 1: Experiment 3 Results

	Z-Max epoxy	**CA20 Ethyl**
Penetration levels of 3DP plaster	Worse	Better x3
General & gradual pressure increase	Good	Good
Local area pressure	Better	Worse
Heat exposure (70°C)	Not affected	Not affected
Penetration levels of 3DP plaster	Z-Max epoxy	CA20 Ethyl

As indicated earlier, the barrier material needs to allow the titanium based silicon (cast material) to cure properly. The following tables demonstrate the results of the two test sessions conducted to find material that prevent inhibition of silicon due to contamination:

Table 2: Experiment 1 Results

	Treated with Z-Max epoxy*	Treatment 2	Manufacturer	Results
000	No	No	NA	Silicon cured and cast released easily but mold is brittle
01A	Yes	Kilz stain blocker	Masterchem Industries	Textured surface with cracks
02A	Yes	crystal clear Acrylic	Krylon	Silicon cured and cast released easily
03A	Yes	B.I.N Shellac base primer	Zinsser	Silicon completely inhibited
04A	Yes	Zinc chromate primer	Plasti-kote	Silicon partially inhibited and cast jammed in mold
05A	Yes	Appliance Epoxy	Krylon	Silicon & epoxy partially inhibited
06A	Yes	Primer	Krylon	Silicon & primer partially inhibited

Table 3: Experiment 2 Results

	Treatment	Manufacturer	Results
01B	Kilz stain blocker	Masterchem Industries	Silicon partially inhibited and cast jammed in mold
02B	crystal clear Acrylic	Krylon	Silicon cured and cast released easily
03B	B.I.N Shellac base primer	Zinsser	Cracks formed when the shellac cured
04B	Zinc chromate primer	Plasti-kote	Silicon cured but cast jammed in mold
05B	Appliance Epoxy	Krylon	Silicon completely inhibited
06B	Primer	Krylon	Silicon cured and stained the mold

Solutions showed varying degrees of effectiveness performing as a barrier. One barrier solution, Krylon's Crystal Clear Acrylic, seemed to perform satisfactorily.

While the tests were capable of revealing the appropriate barrier and strengthening materials for the mold prototypes, it was realized at a late stage of experimentation, that only a barrier between the Z-Max epoxy and the silicon was needed; the final casting process proved a

* Z-Max epoxy is produced by Z Corporation.

minimal need for pressure tested earlier; in fact what was needed was a minimal clamp pressure was needed to hold mold components together. Moreover, it was discovered that while heat accelerated the curing of silicon, it had no other advantage on the process; therefore, molds were left to cure with room temperature.

3.6. The Casting Process

In developing the mold prototypes for the module, the aim was that the cast would bear as little manufacturing marks as possible, for concerns of these might compromise the integrity of the module, and thus the training process. The casting process took place at the Industrial Design Department, as well as in the labs of COMPRU (Craniofacial Osseointegration and Maxillofacial Rehabilitation Unit) rehabilitation unit. Casting at COMPRU occurred with the help of a medical technologist, a medical materials expert, and the presence of a plastic surgeon at times.

The casting process is explained below, although, for better appreciation of the process please refer to Documentation of the Module's Casting Process Video in appendix E on the provided DVD.

3.6.1. Items Needed For Casting Process

- Mold components (as indicated in Figs 3.24, 3.26, and. 3.29).
- FX-304 silicon putty.
- LSR-5 Liquid Silicone Rubber.
- F-901 Separating solution.
- Bone tissue printed in ABS plastic.
- Clamps, mixing and injection apparatus.

3.6.2. Casting the Septal and the Upper Lateral Cartilages

- FX-304 silicon putty was used to cast this part. 10ml for each part mixed thoroughly until color is uniform.

- The curing process of FX-304 silicon putty starts about a minute after the two parts are mixed together and completely cures in about five minutes. It is crucial to have everything needed for casting ready and in arms reach.

Fig 3.31 The mold used to cast the septal and upper lateral cartilage.

- Once the putty is mixed, it is introduced rapidly into the mold. Afterwards, parts are joined and clamped as shown in Fig 3.31

Fig 3.32 FX-304 silicon putty cast in the septal and upper lateral cartilage mold.

- The putty is left to cure for about five minute then released from the mold and the excess putty is cut off.

Fig 3.33 Septal and upper lateral cartilage finished.

3.6.3. Casting the Lower Lateral Cartilages

The process indicated in section 3.6.2 was duplicated to cast the lower lateral cartilages with using their respective molds.

Fig 3.34 Left and right lower lateral cartilages finished.

3.6.4. Casting the Main Mold

- F-901, a separating solution developed by Factor II Inc., was brushed on the ABS print (bone tissue), cartilages and the inner walls of the main mold.

Fig 3.35 F-901, by Factor II Inc.

- All components are colleted and placed into the main mold as indicated in Fig 3.36.

A

B

Fig. 3.36 ABS bone tissue, nasal passage parts, septal and the upper lateral cartilage all in place (A). Lower lateral cartilages in place (B).

- Two equal parts (30ml each) of LSR-5 Liquid Silicone Rubber is mixed thoroughly (using a centrifuge).

Fig 3.37 LSR-5 Liquid Silicone Rubber.

- Before closing the mold some silicon is introduced into it; mostly in tight areas to ensure the even and complete distribution of silicon.

Fig 3.38 Introducing silicon in tight areas.

- Afterwards, the mold is closed and the rest of the silicon introduced through injection.

Fig 3.39 Silicon introduced into the mold.

- The mold is secured with clamps to stop mold parts from shifting.

Fig 3.40 Mold clamped and left to cure over night in room temperature.

- Finally, the mold is left to cure overnight in room temperature.

3.6.5. Releasing the Cast from the Main Mold

The complexity of the inner wall of the main mold demands a particular sequence of cast release, otherwise the mold would rupture the silicon or the intricate parts of the mold itself might break. The release sequence is as follows:

- After releasing the mold from the clamps, the excess silicon which leaked during the curing process is removed from the exterior of the mold.

* The bottom par of the mold is removed first.

Fig 3.41 The bottom part of the mold removed.

* Followed by the upper part of the mold top (see Fig. 3.42).

Fig 3.42 The upper part of the mold top removed.

- The lower part of the mold top is the most difficult part to remove due to the presence of undercuts. First, the cast is released from the walls of the mold. Afterwards, the slow and careful maneuvers indicated in Fig 3.43 would secure a successful release.

Fig 3.43 Releasing the lower part of the mold top.

- Fig 3.44 below illustrates the final cast. The cast is cleaned and retouched as a final step to the casting process.

3.7. Final Production Notes

The entire casting process indicated here was performed three times to ensure the efficiency and the consistency of the process. All trials were successful with negligible variations. The three trials used the same mold which resulted in humidity from the silicon penetrating the barrier coating of the mold. Still, the prototyped mold parts maintained their integrity. It is probable that the mold would eventually

Fig 3.44 The module fresh out of the casting mold.

collapse, after numerous castings performed, if the humidity is not removed from the mold parts. Removing the humidity (by placing the mold parts in an oven with a temperature of 40°C for 12 hours) would likely increase the number of modules obtained from the same mold. It is possible then if a low number of training modules is required that a cheaper 3DP mold could substitute the more expensive but permanent brass or Aluminum mold. A brass or Aluminum mold is recommended for a large scale production.

Chapter 4

Reflections on the Process

4.1. Introduction

In the interest of creating a training module suitable for practicing surgical procedures, providing an intermediate, hands-on, easily accessible and cost-effective training tool, to offer an alternative to traditional approaches of learning standard rhinoplasty procedures including prominent dorsal hump procedure, this chapter will now turn its attention to the results of the project demonstrated in chapter three.

As noted earlier, the development/prototyping stage the module has reached at the conclusion of this study is the initial, or alpha, phase of development. Consequently, the results discussed are in agreement with the development/prototyping stage that the module has reached. The analysis is based on my won observations as well as observations from the supervising surgeon. An empirical and accurate evaluation of the module is recommended for a future study but, at this phase, it is beyond the aims and the scope set for this study.

4.2. A Case for Rapid Prototyping

Prototyping has been a traditional and necessary step in product development of while blueprints, CAD/CAM simulation, and other ideation tools are important. Nevertheless, holding a prototype in

ones own hand can tell much more than any other ideation tool can (Loughlin, 310).

Traditionally, prototyping using clay modeling or numerically controlled machining (NC) has been a time- and labor-intensive process with substantial start-up cost (McMains, 52). As an alternative to those traditional mass-production manufacturing methods, rapid prototyping (RP) has taken some great leaps in the last few years (Loughlin, 310). The arrival of sufficient computational power and CAD software packages that are able to communicate with machines capable of producing voluminous objects have automated the planning phase of manufacturing. RP initially was exclusive to large manufacturing bodies such as military and automotive industries. Gradually and with the advent of powerful desktop computers, the technology has become more affordable to smaller manufacturing entities involved in product development--medical services are no exception. With RP, a designer has the freedom and capability of creating complex objects using CAD software without the need for manual prototyping hence saving time and resources and making way for more creativeness and experimentation.

The following RP machines were considered for the development of the training module: Invision si² 3D printer, Zcorp Spectrum Z510, Viper si² SLA 3D System, EDM technology, and Roland Modela Pro MDX-650. The Zcorp Spectrum Z510 machine three-dimensional printing technology was the choice of 3DP RP. The choice was made for the following reasons:

1. It uses high performance composite powder (Z Corporation, "Products/Printersdetail")—bimodal powder (Lanzetta and Sachs, 157-166); a highly engineered plaster. Plaster is a

historical mold making material with desirable material properties. It is commonly used by medical technicians (Herbert et al., 141-146).

2. It is an additive process that generates no waste and use little more material than the object requires (Bak, 341).

3. Flexible choice of materials compared with other technologies such as StereoLithography (McMains, 53).

4. Near net shape reduces the skills and time needed for multi-part design, and eliminates the need for machining and assembly (Bak, 341).

5. 3DP process doesn't require attached external support structures.

6. User selectable layer thickness between .089-.203 mm with a resolution of 600 x 540 dpi (Z Corporation, "Products/Printersdetail").

7. Faster building speed (McMains, 53); 2 layers per minute ("Products/Printersdetail" Z Corporation).

8. 24-bit color, 3D printing capability option ("Products/Printersdetail" Z Corporation).

9. Printed objects are responsive to manual modifications by means of sanding and carving among others.

10. The porous nature of the finished print allows for further surface treatments.

11. Alterations of physical properties of the 3d print are possible with chemical treatments with no or minimal shape disturbance.

12. Relatively more economical in comparison with other RP options (McMains, 54).

13. Relatively smaller outlets required to remove building material when compared with other technologies (McMains, 56).

The other RP methods considered has the ability to substitute the layered powder solid freeform fabrication (Zcorp Spectrum Z510) with sacrificing one or more of the advantages described above. The Viper si² SLA 3D (System StereoLithography Apparatus) uses thermal-sensitive resin with UV-curing (Hague, Mansour and Saleh, 348). Invision si² 3D printer uses acrylic photopolymer for building and temporary wax system for support (M2 Systems). Roland Modela Pro MDX-650 uses inserts in a subtractive process. EDM (Electrical-Discharge Machining) uses electrical erosion on conductive metals (Wordiq).

The layered powder solid freeform fabrication is not without its disadvantages. While it is more responsive to manual modifications, it is fragile, and without the added step of chemical treatment to strengthen it, its function would be limited to providing visual and tactile feedback. As well, while layered powder process boasts a low margin of error, it is somewhat less accurate with coarser surface finish when compared with other 3DP technologies such as SLA (Wright, 40). Nevertheless, such disadvantages have no detrimental effect on the

parts produced for this project and the advantages of utilizing the layered powder solid freeform fabrication outweigh the disadvantages.

4.3. Designing and Making the Module

> Creative thought process seems particularly difficult to recall…it involves a great deal of appraisal, discarding, selecting, and altering, and sometime changing things around completely…
>
> (Jones; 59-60)

The design process for this project was no different from the description above. A great deal of the design process of this training module occurred by means of employing the available tools creatively not strictly. The pipeline presented in chapter three, for example, (see Fig. 3.6) served as a road-map which introduced general boundaries to the creative process rather than a strict régime. Working within such confines creates a difficulty with fully demonstrating this somewhat subjective and sometimes unconscious design process. Still, I have exerted a great effort to make the design process as transparent as possible to the reader by a multitude of appendices to support my written word.

The design pipeline developed for this study (see section 3.3) conformed to the general development processes and established methodologies for medical prosthetic design. Most of the module components were successfully designed using this pipeline or a slight variation of it.

The decision to seek ‘anatomical correctness’ rather than ‘anatomical accuracy’ for the module was a sound and advantageous

decision. The difficulty with ‘anatomical accuracy’ is that the complexity of the nasal region can bring serious complications to the manufacturing process without adding any noticeable benefits to the training process. In addition, the variations of nasal structures are immense; rendering anatomical accuracy, in this case, as a secondary concern. The decision, therefore simplified an otherwise a very complex region. It also thwarted unnecessary manufacturing complications and effectively made the delivery of a useful training module feasible.

The first iteration had to investigate the simple and the obvious. This iteration had little chance of success but it was necessary to explore in order to dispel all doubt. The molds for the cartilaginous tissues consisted of a simple two-part mold (see fig. 3.21). On the other hand, the main mold was a five-part reverse mold and, as such, it required considerably more time and dedication to model when compared with the cartilaginous molds (see fig. 3.22).

A multipart mold is always a last resort in manufacturing industries due to the exponential cost such molds would impose on steps preceding it, in design and production hence the trial with the first iteration. The second iteration was the crucial step of the development. The parts demonstrated in section 3.3.3.2 were realized after some serious doubts about the feasibility of such a module to be manufactured on a commercial scale due to the previously stated anatomical complexities of the nasal region.

Preliminary casts using the second iteration designs were successful and the cartilaginous tissue molds produced practically flawless casts while the main mold cast had a lower level of success with components sifting their position. Therefore, the third and fourth

iterations consisted of further fine-tuning of molds to improve quality and reduce labor.

The main mold design has evolved to a progressive mold from the reverse mold of the first iteration. It explicitly demonstrated the casting difficulties associated with this part and the considerations required to make such a mold possible. One of the most obvious results of the first iteration trials was that the number of parts that make the main mold grew from five to six in the second iteration. The introduction of an access hatch at the bottom of the base of the mold was added as means to introduce, remove and anchor the nasal passage parts, as well as anchoring the back of septal cartilage. This amendment did not improve the performance the mold and therefore was eliminated in the fourth iteration molds. The nasal passage parts have evolved in the second iteration; in the first iteration, the anchor placement left little doubt that it would be removed with ease once cast (See Fig. 3.21). Therefore, the anchor was moved to a lower and more strategic section to allow ease of removal after casting. This amendment yielded a mold with a better release.

4.4. Examining the Resulting Module

Visually, the overall appearance of the module correctly represents the area of interest in that the exterior of the module is in agreement with the general measurements and portions of human. The nose explicitly demonstrates a prominent dorsal hump condition and the substructures included in the training module are in their correct anatomical position. From a visual stand point, the module demonstrates successfully all the requirements needed to visually imitate a human nose with a prominent dorsal hump condition.

The tactility of the module sufficiently resembles that of a real nose. The material properties of the silicon that constitute the exterior of the module resembles that of human skin in that it flexes and stretches as human skin should. The silicon components that make up the cartilaginous tissues behave similar to that of human cartilage; provide structural support, flexible but not extendable, and responds to realistically to surgical tools. The ABS plastic that makes the bone tissue, as well, performs as desired; it provides the support expected from bone tissue, as well as maintaining similar material properties; it is carvable and susceptible to manual modification.

4.5. Initial Operational Tests on The Training Module

To determine the adequacy of the module as a training alternative for a myriad of standard rhinoplasty procedures, initial tests were conducted on the alpha prototype by the supervising surgeon; Dr. Gordon Wilkes[1] at COMPRU labs. As well, Professor R. Lederer, the study supervisor was in attendance. The duration of the test session was three hours. This test consisted of performing several standard rhinoplasty procedures including dorsal hump rhinoplasty. The entire session was photographed and documented on video.

The overall reaction of Dr. Wilkes to the module at its alpha stage was that it successfully simulated the nose region and provided adequate condition to train on standard rhinoplasty procedures including dorsal hump rhinoplasty. The different tissues simulated behaved adequately in comparison with human tissue, and simulated components responded efficiently to surgical tools and procedures. At

---

[1] Dr. G. Wilkes, Act Div Dir Plastic Surgery. Faculty of Medicine and Dentistry, University of Alberta/COMPRU, Caritas Health Group, Misericordia Community Hospital, 16940-87 Avenue, Edmonton, Alberta, Canada, T5R 4H5. Tel: (780) 735-2660. E-mail: compru@cha.ab.ca

the end of the testing session Dr. Wilkes was provided a questionnaire regarding performance specifics of the alpha module. Below, an abbreviation of the responses is provided—the percentages provided below are out of 100%.

- The visual accuracy of the module scored 80%; while the module, the position of the components and their relationship to one another simulated an anatomically correct nose, the lack of blood made the module less realistic. While posing several challenges, it is worthwhile to investigate the possibility of simulating some of the main arteries of the nasal region and introduce it into the module.

- The efficiency of the module to perform standard rhinoplasty procedures including dorsal hump rhinoplasty scored 80%. Dr. Wilkes indicated some issues in regards to the thickness of in the skin at the cartilaginous pyramid area—it was too thin, and fell outside the correct anatomical variation. As well the anatomy of the bony pyramid tissue of the simulated subject was slightly firmer than normal. While the simulated boney pyramid fell within the correct anatomical variation, the ABS plastic, the material used to make the bone tissue, is denser than bone tissue; hence the firmness. Still the ABS plastic simulated osteotomies realistically and Dr. Wilkes concluded that the ABS plastic is appropriate material to simulate bone tissue. The concerns indicated here can be overcome with relative ease by manually modifying the corresponding area in the CAD files to reflect the needed settings.

- The tactility of the module sufficiently resembling that of a real nose scored 70%; which is a high score considering the artificiality of the whole concept!

- The different module components performance was varied; the bone tissue scored 60% on osteotomy procedure, due to the 'thick boney pyramid' issue denoted previously; the septum performance on the other hand was highly accurate and scored 90%. As for the performance of the lower and upper lateral cartilage, both performed sufficiently and scored 80%. Dr. Wilkes requested no further adjustments for any of the cartilaginous components of the module.

- The response of surgical tool used on the module and their feedback was sufficiently realistic; all module components scored 80% except for the bone tissue; it scored 60% due to the 'thick boney pyramid' issue denoted previously.

- The ability to perform dorsal hump rhinoplasty procedure efficiently scored 70%. While most component performed as expected, the problem with the thin skin at the cartilaginous pyramid area reduced the realism due to the rupture of the simulated skin.

- As for the impression of Dr. Wilkes of the adequacy of the training module to teach standard rhinoplasty procedures including dorsal hump rhinoplasty, the anatomy of the nose; both scored a high 90%. As for the possibility of the use of this module as an experimentation tool, or illustrative purposes, and as a method to examine skill level of surgical trainees; all scored a high 90%.

The final assessment of the training module by Dr. Wilkes indicated the following:

> …an excellent effort to provide in-vitro teaching for a clinical situation; the potential of the module to improve patient care by increasing surgeons' performance level; discern the competence level of a surgeon before embarking on performing complicated and highly technical procedures, such as rhinoplasty, and offer an evidence-based evaluation of such competence.

To best appreciate the performance of the module, the reader is encouraged to review the Documentation of Tests conducted on the Module video in appendix F of the provided DVD.

4.6. Who Would Produce the Training Module

Medical technicians involved in the manufacturing of medical prostheses already use pipelines that resemble the process explained in chapter three. The tools and the expertise needed to develop the training module are therefore already available in health service clinics that offer medical prostheses services. Having the facilities, infrastructures, and trained personnel will certainly minimized the cost of development of this training module and facilitate the development of others. From my observation of work processes in clinics like COMPRU, creating the training module would not be a departure form activates the medical technicians already involved in with prostheses manufacturing. One of the advantages, then, that medical technicians involved in producing this module would draw from their experience in prostheses manufacturing and use similar tools to produce the training module and hence minimizing production costs.

Chapter 5

Conclusions & Recommendations

The Hands-On Rhinoplasty Training Module project was introduced including an elaboration on related research fields, a comparative approach of existing simulation methodologies, and theoretical assessments of training techniques. This was done with the goal of attempting to fully explain the motivation to research and develop simulated training alternatives for surgical trainees. Five explicit objectives have been presented along with their principal problems and suggested solutions.

The methodology implemented for the project was successful in creating an alpha prototype that is hands-on and cost-effective—a tool that would perform as an appropriate physical training module for standard rhinoplasty procedures including a prominent dorsal hump condition. The module provides an opportunity for surgical trainees to learn basic skills by repeating procedures as often as they feel necessary without the need to wait for appropriate patients to appear. This, along low production/replication costs and ease of transport gives the module qualities that are difficult to match by any other available options for surgical trainees—an tremendous ease of access.

The process explained in chapter three, along with supplementary appendices, clearly establish a methodology that would enable future production of similar training modules with different scenarios. Moreover, I have effectively proven the potential of the module to offer a training option that would moderate the steep learning curve for rhinoplasty and provide an evidence-based assessment tool to assess the competency of surgical trainees and their development. If incorporated efficiently into examination situations, the module would provide sufficiently structured and consistent evaluation of surgical competence, as well as providing inexpensive and reliable format to evaluate candidates for surgical training. All would arguably deliver more competent surgeons and decrease medical errors.

The subsequent development stage for the Hands-On Rhinoplasty Training Module, beta stage, will perform a series evaluations on the prototype, such as the one performed by Dr. Wilkes. It is recommended that such evaluation to be conducted on a larger scale. The statistics gathered from such evaluations would provide a great insight into the reactions of surgical professional, shortcoming of the module, and recommendations on possible applications. Gathering such information would definitely aid in perfecting future versions of the module. Furthermore, the beta stage will address the concerns regarding performance denoted in chapter four evaluations, as well as develop/consider the options to market the module, diffuse its benefits on the surgical community, and assist in future development.

Bibliography:

Aldrich, Clark. Learning by doing: a comprehensive guide to simulations, computer games, and pedagogy in e-learning and other educational experiences. San Francisco: Pfeiffer, 2005.

Bak, David. “Rapid Prototyping or Rapid Production? 3D Printing Processes Move Industry Twards the Latter”. Assembly Automation. Vol. 23:4 (2003): 340-346.

Batteau, Lukas M., et al. “A Study on the Perception of Haptics in Surgical Simulation”. Medical Simulation. Eds. Cotin, Stéphane, and Dimitris Metaxas. Proc. of the International Symposium, ISMS 2004, Cambridge, MA, USA, 17-18, June 2004. New York: Springer, 2004. 185-192.

Bryson, Steve. “Virtual reality in scientific visualization.” Communications of the ACM Archive Vol. 39:5 (May 1996): 62 – 71. 19 Feb. 2006 < http://portal.acm.org/citation.cfm?id=229467&dl=ACM&coll=portal>

CBC. Taintedblood Page. 30 May. 2005. 29 Apr. 2006 <http://www.cbc.ca/news/background/taintedblood/>

C ideas. Prototype3d Page. 1998. 14 Mar. 2006 < http://www.prototype3d.com/a_html/rp.html>

Dath, Deepak, and Richard Reznick. “Objectifying skills assessment: Bench model solutions.” Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 52-66.

De Cossart, Linda, and Della Fish. Cultivating a Thinking Surgeon: New Perspectives on Clinical Teaching, Learning and Assessment. United Kingdom: Castle Hill Barns, 2005.

Dilworth, Robert Lex, and Verna J. Willis. Action learning : images and pathways. Florida: Krieger Pub., 2003.

Dimon, Theodore Jr. The Elements of Skill: A Conscious Approach to Learning. California: North Atlantic Books, 2003.

Donaldson, Liam J. "Clinical Performance in the National Health Service". Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 17-29.

Electronic Visualization Laboratory. Index Page. University of Illinois in Chicago. 19 Jan. 2006. <http://www.evl.uic.edu/core.php>

Ellis, Harold. A History of Surgery. London: Greenwich Medical Media Limited, 2002.

Factor II Inc. Catalog/specialty Page. 2005. 10 Apr. 2006 <http://www.factor2.com/catalog/specialty_175332_products.htm>

---. Catalog/platinum Page. 2005. 10 Apr. 2006 < http://www.factor2.com/catalog/platinum_175331_products.htm >

Goldwyn, Robert M. "The Genesis of Juris Imprudence." Plastic and Reconstructive Surgery. Vol. 114(&NA;) (Oct. 2004): 18

Goode, A.W. "The Clinical Link". Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 91-108.

Hague Richard, Saeed Mansour and Naguib Saleh. "Design opportunities with rapid manufacturing". Assembly Automation. Vol. 23:4 (2003): 346 – 357.

Herbert, Nicholas, et al. "A preliminary investigation into the development of 3-D printing of prosthetic sockets". Jounal of Rehabilitation Research & Development. Vol. 42:2 (March/April 2005):141 – 146. 12 Dec. 2005 < http://www.vard.org/jour/05/42/2/herbert.html>

Hughes, Frank E. “Proficiency Training for Space Flight”. Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 73-80.

ISMS. International Symposium on Medical Simulation. Jun 17-18, 2004. The Simulation Group. 19 Jan. 2006. <http://www.medicalsim.org/symposium2004/>

Jones, Ken. Simulations: a handbook for teachers and trainers. 3rd ed. London: Kogan Page; New Jersey: Nichols Pub. Co., 1995.

Lanzetta, Michele, and Emanuel Sachs. “Improved surface finish in 3D printing using bimodal powder distribution”. Rapid Prototyping Journal. Vol. 9:3 (2003):157-167.

Liu, Yi, Amy E. Kerdok, and Robert D. Howe. “A Nonlinear Finite Element Model of Soft Tissue Indentation”. Medical Simulation. Eds. Cotin, Stéphane, and Dimitris Metaxas. Proc. of the International Symposium, ISMS 2004, Cambridge, MA, USA, 17-18, June 2004. New York: Springer, 2004. 67-76.

Loughlin, Clive. “Rapid prototyping - just starting, or nearing the end?”. Assembly Automation. Vol. 23:4 (2003): 310.

M2 Systems. Prototyping/invision Page. 2005. 17 Sep. 2005 <http://www.m2-systems.com/prototyping/invision.php>

Mackway-Jones, Kevin, and Mike Walker, eds. The pocket guide to teaching for medical instructors. London: BMJ Books, 1999.

Materialise. Home Page. 2005. 19 Sep. 2004 <http://materialise.com/HOME/home_ENG.html>

McGill, Ian, Anne Brockbank. The Action Learning Handbook: Powerful Techniques for Education, professional Development and Training. London: RoutledgeFalmer, 2004.

McMains, Sara. “Layered manufacturing technologies”. Communications of the ACM Archive Vol. 48:6 (June 2005): 50 – 56. 19 Feb. 2006 <http://portal.acm.org/citation.cfm?id=1064830.1064858&coll=GUIDE&dl=GUIDE&idx=J79&part=periodical&WantType=periodical&title=Communications%20of%20the%20ACM>

MMVR. Medicine Meets Virtual Reality 15. Feb 6-9 2007. Aligned Management Associates, Inc. 19 Jan. 2006 <http://www.nextmed.com/mmvr_virtual_reality.html>

Newble, David, and Lesley Southgate. “The Principles and Practice of Assessing Clinical Competence”. Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 30-51.

NLM. The Visible Human Project® Overview Page. 11 Sep. 2003. United States National Library of Medicine, National Institutes of Health. 18 Feb. 2006 <http://www.nlm.nih.gov/research/visible/visible_human.html>

Pappo, Harry A. Simulations for skills training. Englewood Cliffs, N.J. : Educational Technology Publications, 1998.

RadiologyInfo. Computed Tomography Page. 21 Jun. 2005. 8 Feb. 2006 <http://www.radiologyinfo.org/content/ct_of_the_body.htm>

Pham, D.T., and S.S. Dimov. Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling. London: Springer, 2001

Richards, Sir Rex, “Why Do We Need to Assess Competence? Surgical Competence: Challenges of Assessment in Training and Practice. Eds. Royal College of Surgeons of England/Smith and Nephew Foundation. London: Royal College of Surgeons of England, 1999. 6-16.

Samalonis, Lisa B. “How to effectively market your practice: personal touches, relaxed atmosphere help patient retention.” Cosmetic Surgery Times. Apr. 2005. Retrieved from www.findarticles.com 20 Jan. 2006 <http://www.findarticles.com/p/articles/mi_m0HMW/is_3_8/ai_n13786186>

Sawchuk, Peter H. Adult Learning and Technology in Working-Class Life. United Kingdom: Cambridge University Press, 2003.

Schön, Donald A. The Reflective Practitioner: How Professionals Think in Action. USA: Basic Book, Inc., 1983.

---. Educating the Reflective Practitioner: Tward a New Design for Teaching and Learning in the Professions. San Francisco: Jossey-Bass Publishers, 1987.

SDSC. Tele-Manufacturing Facility Project Page. San Diego: University of California. 8 Feb. 2006 <http://www.sdsc.edu/tmf/Stl-specs/stl.html>

Simulab Corporation. AboutUs Page. 2004. 19 Jan. 2006. <http://www.simulab.com/AboutUs.htm>

Smith, Lee E., and Patricia Beatty. "The Practice of Medicine and Its Interface With Medical Regulation." ARCH FACIAL PLAST SURG Vol. 1 (Jan-Mar 1999): 58-59. Retrieved from www.archfacial.com 16 Jan. 2006.

SUMMIT. Research Page. Stanford University Medical Media & Information Technologies, 2002. 19 Jan. 2006 <http://summit.stanford.edu/research/current.html>

Sutherland, L.M., et al. Surgical Simulation: a Systematic Review. ASERNIP-S Report No. 29. South Australia: ASERNIP-S, 2003.

Tomporowski, Phillip D. The Psychology of Skill: A Life-Span Approach. London: Praeger, 2003.

Towne, Douglas M. Learning and instruction in simulation environments. Englewood Cliffs, N.J.: Educational Technology Publications, 1995.

UMM. Cosmetic Nose Surgery Page. 14 Feb. 2005. Rev. Molmenti, Hebe. University of Maryland Medical Center. 18 Feb. 2006 <http://www.umm.edu/ency/article/002983.htm>

Van Pinxteren, Sors A. T., et al. “Interest in Facial Plastic and Reconstructive Surgery Among Otorhinolaryngologists: A Survey in the Netherlands.” ARCH FACIAL PLAST SURG Vol. 7 (Mar-Apr 2005): 138-142. Retrieved from www.archfacial.com 16 Jan. 2006.

Vartanian. A. John, et al. “The Virtual Nose: A 3-Dimensional Virtual Reality Model of the Human Nose.” ARCH FACIAL PLAST SURG Vol. 6 (Sep-Apr 2004): 328-333. Retrieved from www.archfacial.com 18 Aug. 2005.

Veeramachaneni, Nirmal K. “OR Conduct”. Surgery Survival Guide. Eds. Goodman, Jeremy, et al. Philadelphia: Lippincott Williams & Wilkins, 2003. 48-49.

Verdine, Benjamin W., and Aaron G. Grand. “Plastic Surgery Essential”. Surgery Survival Guide. Eds. Goodman, Jeremy, et al. Philadelphia: Lippincott Williams & Wilkins, 2003. 253-254.

Webopedia. Hpptic Page. 09 Oct. 2005 <http://www.webopedia.com/TERM/H/haptic.html>

Wordiq. Wire_EDM Page. 2004. 03 Mar. 2006 <http://www.wordiq.com/definition/Wire_EDM>

Wright, Paul K. “Rapid prototyping in consumer product design”. Communications of the ACM archive. Vol. 48:6 (June 2005): 36 – 41. 14 Dec. 2005 <http://portal.acm.org/citation.cfm?id=1064830.1064856&coll=GUIDE&dl=GUIDE&idx=J79&part=periodical&WantType=periodical&title=Communications%20of%20the%20ACM>

Z Corporation. Home Page. 2006. 15 Sept. 2005 <http://www.zcorp.com/home.asp>

---. Products/Printersdetail Page. 2006. 15 Sept. 2005 <http://www.zcorp.com/products/printersdetail.asp?ID=2>

Appendices

- Appendix A: Contact Information of Foundries & Correspondence

Material on CD

- Appendix B: Material Data Sheets
- Appendix C: Digital Copy of the Thesis Document
- Appendix D: Documentation of Intraoperative Rhinoplasty Operations

Material on DVD

- Appendix E: Documentation of the Module's Casting Process
- Appendix F: Documentation of Tests conducted on the Module

Appendix A

Contact Information of Foundries & Correspondence

- Contact Information of Foundries
- E-mail Correspondence

Certification level	Certified in	Company	First name	Last name	Street Address	City	State	Zip Code	Phone	Email	Partner Since
Gold	ZCast	Clemson University	Donald	Erich	100 Technology Drive	Anderson	SC	29625	(864)646-2413 x 207	derich@clemson.edu	5/1/2005
Gold	ZCast	Dent Manufacturing	Tim	Dodge	P.O. Box 470	Northampton	PA	18067	(610)262-6701	tdodge@dent-mfg.com	1/27/2004
Gold	ZCast	Fonderie Poitras (Poitras Foundry)	Claude	Masse	12, 5 Avenue	C.P. 280, L'Islet	Quebec	G0R 2C0	(418)247-5041	mariof@scmf.ca	12/18/2003
Gold	ZCast	General Pattern	Tom	Carr	3075 84th Lane N.E.	Blaine	MN	55449	(763)780-3518	dre and@genera pattern com	12/18/2003
Gold	ZCast	Griffin Industries	Dan	Marks	1898 Pride Terrace	Green Bay	WI	54313	(920)434-4440	www.griffinweb.com	12/18/2003
Gold	Investment casting	Sturm	Tim	Murphy	1305 Main	Barboursville	WV	25504	(800)624-3845	tim murphy@sulzerpumps.com	12/18/2003
Gold	ZCast	University of Minnesota - NRRI	Bjorn	Ojard	5013 Miller Trunk Highway	Duluth	MN	55811-1442	(218)720-4261	bojard@nrri.umn.edu	3/14/2005
Silver **	ZCast	3D Rapid Prototyping	Frank	Kurisu	17905 Metzler Lane	Huntington Beach	CA	92647	(714)848-4559	fkurisu@soldermask.com	1/15/2005
Bronze **	ZCast	AlumaCast, Inc.	Cory	Read	3629 Medford Street	Los Angeles	CA	90063	(323)261-6404		1/15/2005
Silver	ZCast	Advanced Technologies 3D Creations	Tim	Reher	6605 101 St. NW	Gig Harbor	WA	98322	(253)549-5224	tim@print3d.net	12/18/2003
Silver	ZCast	Advanced Wireless Technologies Inc.	Shawn	Cherewick	31098 Deertrail Avenue	Abbotsford	BC	V2T 5J6	(604)852-9090	shawn@advancedwirelesstech.com	3/24/2005
Silver **	ZCast	Caterpillar Inc.	Joe	Taylor	14009 Old Galena Rd	Mossville	IL	61552	(309)578-2852	taylor joe h@cat.com	Gold Pending
Bronze **	ZCast	Performance Pattern	Tom	Herman	2421 S.W. Adams	Peoria	IL	61602	(309)676-0907	tomh@performance-pattern.com	Gold Pending
Silver	ZCast	Omega Design	Alan	Coello	365 Blodgett Street, STE B	Cotati	CA	94934	(707)795-7530	sales@omegadg.com	6/21/2005
Bronze	ZCast	Blaylock Industries, Inc.	Frank	Mackey	5532 Midway Road	Fort Worth	TX	76117	(817)831-0170	fmackey@blaylockind.com	12/18/2003
Bronze	ZCast	Burlington Foundry	Kurt	Marvin	13 Adams Street	Burlington	MA	01803	(781)272-1182		1/27/2004
Bronze	ZCast	Cast Technologies	Bret	Markum	1100 S.W. Washington Street	Peoria	IL	61653-0959	(309)676-2157	ct.@ocslink.com	5/18/2004
Bronze	ZCast	Custom Aluminum Foundry, Ltd.	Roy	Butler	458 Dobbie Drive	Cambridge	Ontario	N1T1S7	(519)624-9997	Roy@customaluminum.com	12/18/2003
Bronze	Investment casting	Intermount Precision Castings	Larry	Beenker	1156 West 400 North	Lindon	UT	84042	(801)785-0233	www.ip-casting.com	12/30/2003
Bronze	ZCast / Investment casting	Jacob Pattern Works	Jim	Jacob	449 Old Reading Pike	Pottstown	PA	19464	(610)326-1100		1/2/2004
Bronze	Zcast	LaSalle Foundry & Machine	David	Weaver	1221 Wordsworth	Ferndale	MI	48220	(248)548-5550	sales@lasallefoundry.com	12/18/2003
Bronze	Zcast	Laurel Aluminum Castings	Rich	Starko	12 Allegeny Sqaure	Glassport	PA	15045	(412)673-4700		12/18/2003
Bronze	Zcast	Lovson Exports LTD.	Babita	Babita	98, Bajaj Bhavan, Narivan Point	Mumbai	India	400 021	+91 22 2202 4071	export@lovson.co.in	12/14/2004
Bronze	ZCast / Investment casting	Matrix Industries	Peter	Hnatishin	1585 Dgalb	Winnipeg, Manitoba	Manitoba	R2J 0H3	(204)661-6002	mii@mts.net	
Bronze	ZCast	Pacific Mako	Brad	Vanderlinde	5481 268 Street	Langley	BC	V4W 3W1	(604)856-6668	bradvan@pacmak.com	4/12/2005
Bronze	ZCast	Palmer Foundry	Bob	Logan	22 Mount Dumplin Road	Palmer	MA	01069	(413)283-2976		12/18/2003
Bronze	ZCast	Prototype Castings	Brett	Peak	4696 Ironton Street	Denver	CO	80239	(303)574-0060	brett@protcast.com	12/18/2003
Bronze	ZCast	Radial International / Casting Techn.	Ron	Landau	70 Pennsylvania Avenue	Kearny	NJ	07032	(973)344-0333	rccfoundry@aol.com	1/27/2004
Bronze	Investment casting	Richwood Investment Castings	George	Houston	P.O. Box 1298	Huntington	WV	25714	(304)525-5436	gh@xcellpremet.com	12/23/2003
Bronze	ZCast	Scitech Rapid Solutions	Mike	Ettleson	13 Hampshire Drive	Hudson	NH	03051-4917	(603)577-9970	www.brookfld.com	12/18/2003
Bronze	Investment casting	Shellcast Foundries, Inc.	Bob	Pearson	10645 Lamoureux Ave.	Montreal North	QE	H1G 5L4	(514)322-3760	bobp@shellcast.com	12/18/2003
Bronze	Investment casting	Texcast Inc.	Gary	Hinds	706 Lehman	Houston	TX	77018	(713)697-8006	garyhinds@texcast.com	12/18/2003
Bronze	ZCast	WGB Industries	Erik	Woodward	233 Fillmore Avenue	Tonowanda	NY	14150-0410	(716)693-5527		12/18/2003

** - A lack of borders between vendors indicates a partnership

Inbox Empty Trash Compose Folders Search Address Book Options Problem Open Folder Inbox

Help Log out

Inbox: RE: Casting Cost Estimate (57 of 403)

Mark as: Move | Copy This message to Back to Inbox

Delete | Reply | Forward | Redirect | View Thread | Message Source | Save as | Print | Report as Spam

Date: Thu, 23 Mar 2006 11:03:41 -0500 [03/23/06 09:03:41 MDT]
From: Donald Erich <derich@CLEMSON.EDU>
To: gzabaneh@ualberta.ca
Subject: RE: Casting Cost Estimate
Headers: Show All Headers

Thank you. - Don

-----Original Message-----
From: gzabaneh@ualberta.ca [mailto:gzabaneh@ualberta.ca]
Sent: Thursday, March 23, 2006 10:57 AM
To: Donald Erich
Subject: RE: Casting Cost Estimate

Dear Mr. Erich,

Please accept my apologies for the delay. We have decided to postpone ordering the items discussed earlier until further notice. I will contact you once few issues are resolved. Please note that your questionnaire is attached and completed.

Thank you
Ghassan zabaneh

Quoting Donald Erich <derich@CLEMSON.EDU>:

[Hide Quoted Text]
> Hello Dr. Zabaneh,
>
> Is there any progress on this request? It would be very helpful if
> you could answer the few questions on the attached questionnaire.
>
> Regards,
>
> Don Erich
>
> -----Original Message-----
> From: Don Erich [mailto:derich@CLEMSON.EDU]
> Sent: Wednesday, February 22, 2006 12:52 PM
> To: gzabaneh@ualberta.ca
> Subject: RE: Casting Cost Estimate
>
> Dear Dr. Zabaneh,
>
> Resin bonded sand should not be a problem. I will await your modified
> files and further information.
>
> Regards,
>
> Don Erich
>
> -----Original Message-----
> From: gzabaneh@ualberta.ca [mailto:gzabaneh@ualberta.ca]
> Sent: Wednesday, February 22, 2006 12:35 PM

> To: derich@CLEMSON.EDU
> Subject: Re: Casting Cost Estimate
>
> Dear Mr. Erich,
>
> Thank you for the Estimate. The project supervisor is away this week,
> I need to get his approval before I give you the green light and
> arrange for a payment.
>
From the images you've sent me it seems that the resin bonded sand
> yields a better result. If you think that the it is possible to cast
> these parts with the resin bonded sand then I'll probably ask you to do it
that way.
>
> There will be some minor revisions for the parts you already have; I
> will provide you with the finalized files as soon as I get the go
> ahead from the project supervisor. I will get back to you in about 2 weeks
time.
[Hide Quoted Text]
>
> Thank you
> Ghassan ZabanehQuoting Don Erich <derich@clemson.edu>:
>
>> Dear Dr. Zabaneh,
>>
>> Per your request, I have estimated the cost to prepare 3 castings of
>> your parts in either brass or aluminum. The cost breakdown is as
follows:
[Hide Quoted Text]
>>
>> Print molds for 3 pieces in Z-Cast material - $280
>> Melting prep, casting & removal of gating - $320*
>> Total - $600
>>
>> *This is a rough clean-up. We will cut off all gating but will not
>> grind the parts. Removal of gating and vent contact material where
>> it touches the parts, and removal of any flash is not included. We
>> can do this for you at an hourly rate of $30. I would expect this to
>> take less than 2 hours for all 3 parts.
>>
>> Neither print costs nor casting costs increase linearly. That is,
>> costs will rise at a slower rate the more parts we cast at one time.
>> We cannot guarantee that the parts will be suitable for your intended
>> use, only that we will make a best-efforts attempt to satisfy your needs.
>>
>> The Z-Cast mold material produces castings that have a surface finish
>> similar to standard sand casting. We also use a resin bonded sand,
>> which gives better surface finish and picks up more detail. The two
>> images below show a casting that we've prepared using both approaches.
>> The resin bonded sand mold was used for the part shown first, the
>> Z-Cast mold for the second part. If you are interested in having us
>> do this work for you, please let me know which approach you prefer.
>> I haven't estimated the cost using the resin bonded sand. If you are
>> interested in this approach, let me know and I will provide you with
>> a
> revised cost estimate.
>>
>> Regards,
>>
>> Don Erich
>>
>> Resin Bonded Sand Mold Z-Cast Mold
>>
>>

>> Donald L. Erich
>> Director
>> CETL
>> 100 Technology Drive
>> Anderson, SC 29625
>>
>> 864-646-2413 x207
>> 864-656-7310 FAX
>> 678-469-2385 CELL
>> visit us on the web at www.cetl.org
>>
>>
>>
>>
>

Delete | Reply | Forward | Redirect | View Thread | Message Source | Save as | Print | Report as Spam

Mark as: Move | Copy | This message to Back to Inbox


Appendices B, C and D
Ghassan Zabaneh
Appendices E+F
FUJIFILM
DVD+R
FOR DATA AND VIDEO
4.7 GB / 120 Min